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CAPSTONE PROJECT REPORT

JOINT TERMINAL ATTACK CONTROLLER SENSORS AND LASERS MODERNIZATION

by

311-1110 Team Quantico

September 2012

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13. ABSTRACT (maximum 200 words)

Inconsistencies exist among components of current ground targeting equipment because they were all fielded at different times and with different Concepts of Operations. This has caused an impractical design trade space resulting in unclear requirements that are inconsistent with either state of the art technology or a threat analysis of all possible combat situations. The Joint Terminal Attack Controller Sensors and Lasers Modernization capstone project was started to provide models, trade spaces, and a technology roadmap/modernization plan that will guide future development of equipment belonging to the Tactical Air Control Party suite of equipment. The process used for the project was to gather all of the requirements in one consolidated list and prioritize it based upon user representative feedback. This list, with current Science and Technology efforts, was used to provide data points corresponding to future technology improvements and determine whether or not those improvements will add value to the end user. Based upon this project it was found, somewhat surprisingly, that the most valued system characteristic is Target Location Error, followed by Weight and Target Designation Range. It was also found that both Mid Wave Infrared and Short Wave Infrared technologies are most promising compared to Long Wave Infrared.

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JOINT TERMINAL ATTACK CONTROLLERS SENSORS AND LASERS MODERNIZATION

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Inconsistencies exist among components of current ground targeting equipment because they were all fielded at different times and with different Concepts of Operations. This has caused an impractical design trade space resulting in unclear requirements that are inconsistent with either state of the art technology or a threat analysis of all possible combat situations. The Joint Terminal Attack Controller Sensors and Lasers Modernization capstone project was started to provide models, trade spaces, and a technology roadmap/modernization plan that will guide future development of equipment belonging to the Tactical Air Control Party suite of equipment. The process used for the project was to gather all of the requirements in one consolidated list and prioritize it based upon user representative feedback. This list, with current Science and Technology efforts, was used to provide data points corresponding to future technology improvements and determine whether or not those improvements will add value to the end user. Based upon this project it was found, somewhat surprisingly, that the most valued system characteristic is Target Location Error, followed by Weight and Target Designation Range. It was also found that both Mid Wave Infrared and Short Wave Infrared technologies are most promising compared to Long Wave Infrared.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AFATDS	Advanced Field Artillery Tactical Data System
AIM	Azimuth and Inertial MEMS
AirO	Air Officer
AMRDEC	Aviation and Missile Research Development and Engineering Center
AoA	Analysis of Alternatives
APL	Applied Physics Laboratory
AFSS	Armor and Fire Support Systems
C4	Command, Control, Communications, and Computers
CAS	Close Air Support
CD&I	Combat Development and Integration
CLRF	Common Laser Range Finder
CLRF-IC	Common Laser Range Finder Integrated Capability
CONOPS	Concept of Operations
DACT	Digital Automated Communication Terminal
DAGR	Defense Advanced GPS Receiver
DARPA	Defense Advanced Research Projects Agency
DMC	Digital Magnetic Compass
DoD	Department of Defense
DVO	Direct View Optics
ECP	Engineering Change Proposal
FAC	Forward Air Controller
FFBD	Functional Flow Block Diagram

FMID	Fires and Maneuver Integration Division
FO	Forward Observer
FoS	Family of Systems
FSCC	Fire Support Coordination Center
FSS	Fire Support Systems
FY	Fiscal Year
GPS	Global Positioning System
HgCdTe	Mercury Cadmium Telluride
I^2	Image Intensifier
ICD	Initial Capabilities Document
IDNST	Integrated Day/Night Sight Technology
InGaAs	Indium Gallium Arsenide
IPR	In Process Review
IR	Infrared
IZLID	Infrared Zoom Laser Illuminator Designator
JPASS	Joint Precision Azimuth Sensing Symposium
JTAC	Joint Terminal Attack Controller
JTAC-LTD	Joint Terminal Attack Controller Laser Target Designator
JTAC-SLM	Joint Terminal Attack Controller Sensors and Lasers Modernization
LCCE	Life Cycle Cost Estimate
LLDR	Lightweight Laser Designator Rangefinder
LRF	Laser Range Finder
LWIR	Long Wave Infrared
MAGTF	Marine Air Ground Task Force

MCCDC	Marine Corps Combat Development Command
MCOTEA	Marine Corps Operational Test and Evaluation Activity
MCSC	Marine Corps Systems Command
MCT	Marine Corps Task
MCTL	Marine Corps Task List
MEMS	MicroElectroMechanical Systems
MOE	Measures of Effectiveness
MOP	Measures of Performance
MRL	Manufacturing Readiness Level
MWIR	Mid Wave Infrared
N2	N-Squared
NATO	North Atlantic Treaty Organization
NDIA	National Defense Industrial Association
NFCS	Naval Fire Control System
NGF	Naval Gunfire
NGFS	Naval Gunfire Spotter
NGLO	Naval Gunfire Liaison Officer
NIR	Near Infrared
NPS	Naval Postgraduate School
NSFS	Naval Surface Fire Support
NSWCDD	Naval Surface Warfare Center Dahlgren Division
NVESD	Night Vision Electronic Systems Directorate
NVThermIP	Night Vision Thermal and Image Processing
OAG	Operational Advisory Group

ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
PLDR	Portable Lightweight Laser Designator
PdM	Product Manager
PM	Program Manager
PM FSS	Product Manager Fire Support Systems
PMO	Program Management Office
POM	Program Objective Memorandum
POR	Program of Record
PVS	Passive Vision Sight
R&D	Research and Development
RTM	Requirements Traceability Matrix
S&T	Science and Technology
SAASM	Selective Availability Anti-Spoofing Module
SBIR	Small Business Innovation Research
SINCGARS	Single Channel Ground and Airborne Radio System
SME	Subject Matter Expert
SOCOM	Special Operations Command
SSCamIP	Solid State Camera and Image Processing
STOs	Science and Technology Objectives
SWaP	Size, Weight and Power
SWIR	Short Wave Infrared
TACP	Tactical Air Control Party
TEC	Thermal Electric Cooler

TLE	Target Location Error
TLSI	Thermal Laser Spot Imager
TRL	Technology Readiness Level
TRMP	Technology Roadmap/Modernization Plan
TTA	Technology Transition Agreement
U.S.	United States
USMC	United States Marine Corps
UUNS	Urgent Universal Needs Statement

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EXECUTIVE SUMMARY

The motivations behind the Joint Terminal Attack Controller Sensors and Lasers Modernization (JTAC-SLM) project were to improve the current understanding of the requirements and to clarify inconsistencies within the family of target locator systems; and to transition the findings into a useable product that could be used by the requirements development agency, the Marine Corps Combat Development and Integration (CD&I), and the Marine Corps Systems Command (MCSC) Program Management Office (PMO). The requirements for several different systems were inconsistent across many parameters, including range, target location error, and even terminology; however, these different systems were fielded over a long span of time, focusing on what was then the state of the art, and utilizing completely different technologies.

The overall process used for the project was to gather all of the requirements in one useable and manageable consolidated list, obtain user representative feedback to confirm the completeness of the list, obtain end user input to determine the priority of items on the list, use the prioritized list along with current Science and Technology (S&T) efforts to provide data points corresponding to future potential technology improvements and whether or not those improvements, and finally determine whether or not those improvements will add substantial value to the end user.

This project was based on current technologies as well as projected results from S&T investments and efforts. Future efforts will be based upon the results of this research and additional technologies will be explored to open the design window further. If new technologies emerge that were not represented in this project, the real solution may in fact end up better than what is predicted. Conversely, if any of the technologies do not materialize within the commercial market, the end systems may be cost prohibitive. Other future efforts should focus on the commercial market, as it is what drives the end item cost on most optical systems.

The key points from this project include the relative importance of specific parameters, the apparent best value S&T investments, and some insights into the direction of this technology. For example:

- Mid Wave Infrared (MWIR) and Short Wave Infrared (SWIR) are both promising technologies, and warrant further research and development.

- Night Vision technologies can also improve the overall preferences of the systems by reducing the end system weight, as night vision optics is one of the major weight drivers of the end system.

- The most valued characteristic to the end user was Target Location Error (TLE). This allows for the most accurate targeting data to be provided to artillery and aircraft, which is the primary objective of the family of systems.

- Weight was the second most valued characteristic to the end user, and ranges for different missions, such as night or day, followed. A large contribution to weight came from night vision optics.

Finalized products of this project are a Technology Roadmap/Modernization Plan (TRMP) and a value hierarchy of the system. The TRMP predicts availability of future technologies that are applicable to the TACP suite and provides recommendations to Office of Naval Research (ONR) for new efforts in support of the TACP future plans. The value hierarchy presents the preference of each system based upon the survey data collected from the end users. These two elements were combined to reveal which technologies would have the greatest preference among end users and which technologies were unlikely to have better user reception.

As a result of this project, future systems under early development will have both a methodology for revising requirements and seeking user feedback, as well as a current understanding of what future technologies may be incorporated. Ultimately, this will lead to more consolidated requirements as well as expectations of what impact future systems may have on the Joint Terminal Attack Controller (JTAC) equipment suite.

ACKNOWLEDGMENTS

We would like to acknowledge all of the Joint Terminal Attack Sensors and Laser Modernization project stakeholders, especially United States Marine Corps (USMC) Captain Justin Twigg who assisted us greatly by championing our user survey and helping us obtain valuable feedback from actual users of the Joint Terminal Attack Controller system for the intent purpose of determining the key requirements for the project.

We also thank our competency lead engineers, program managers and coworkers who have accommodated, stimulated and encouraged us along in this Master's degree program over these last two trying years.

Team Quantico would like to acknowledge our Naval Postgraduate School Professors, who have taught, trained, directed, and encouraged us all.

Undoubtedly our wives, children and families are to be acknowledged for their patience and support during the many hours, days and weeks devoted specifically to this capstone project. We owe them all much gratitude.

Finally, we honor the Lord God Almighty, Creator of the universe and the source of all true wisdom and knowledge for sustaining us and empowering us through this capstone project and Master's degree program. "The fear of the Lord is the beginning of wisdom, and the knowledge of the holy is understanding" [1].

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I. INTRODUCTION

As dusk approaches in central Afghanistan, a USMC fire team prepares for night operations against the Taliban. The day before, suicide bombers trained by the Taliban killed women and children at the entrance of a school building in Kandahar in opposition to the formal education of girls in Afghanistan. The USMC fire team has received a lead on the Taliban location responsible for orchestrating this attack and therefore must move quickly in order to respond before the Taliban moves out of their hideout. They choose to equip themselves with a laser rangefinder with laser target designator in order to determine the target location and “hand-off” those coordinates to fire support. In order for the fire team to move quickly the laser rangefinder must have sufficient target recognition range for night operations, a small target location error, a sufficient laser imaging range, and be lightweight. With the many different possible battle engagement scenarios and wide range of laser range finder products, the choice for which system to best outfit the fire team for optimal performance becomes complicated where mission success is an imperative.

The Joint Terminal Attack Controller Sensors and Lasers Modernization (JTAC-SLM) capstone project resulted in models, trade spaces, and a Technology Roadmap/Modernization Plan (TRMP) that will guide future development of equipment belonging to the Tactical Air Control Party (TACP) suite of equipment.

This project used a phased approach which is summarized here. The research phase began with the examination the functions performed by Joint Terminal Attack Controllers (JTACs), Forward Observers (FOs), and Naval Gunfire Spotters (NGFS), the requirements and capabilities of current equipment, and planned technology insertions. This information, along with input from stakeholders and Subject Matter Experts (SMEs) was used to determine the key system functions and trade space limitations that guided the Analysis of Alternatives (AoA) phase. The AoA phase included an examination of the trade spaces and the limitations of physics within technology to determine the characteristics of virtual systems built up to meet these functions. Once the list of candidate virtual systems was winnowed, the TRMP was developed to guide the development of the actual systems. This included recommendations for new and ongoing technology development, technology insertion points, and a risk analysis. These products will be useful to guide the modernization of existing TACP equipment, as well as the development of the next generation of the TACP suite.

A. BACKGROUND

The USMC JTACs are charged with the mission to support troops in contact with Close Air Support (CAS). To accomplish this mission, the JTAC has a variety of equipment at his disposal, known as the TACP suite of equipment.

The TACP suite is a kit of equipment that provides overlapping and complementary capabilities, including day and night observation, target identification, target location, self-location, visible and infrared (IR) laser pointers, laser designation, laser spot imaging, data processing, and communications. This suite of equipment is also a mix of Programs of Record (PoR) and rapid fielding under Urgent Universal Needs Statements (UUNS), procured at different times and at different phases of their service life.

The optics and lasers have a high degree of overlap. All of the systems, except for the fielded IR laser pointer, have some sort of observation optic coupled to the rest of the functions that the piece of equipment supports. For example, the Common Laser Range Finder (CLRF), Portable Lightweight Laser Designator (PLDR), Thermal Laser Spot Imager (TLSI), Joint Terminal Attack Controller Laser Target Designator (JTAC-LTD), and Passive Vision Sight (PVS) PVS-14 Image Intensifier all include some sort of observation optic, with differing degrees of capability with respect to target identification range during day and night. There are additional areas of overlap with respect to self-location, integrated laser pointers, range finding, and others. In order to be capable of executing all the missions that JTAC/Forward Air Controller (FAC)/FO is responsible for, the combined weight of the entire JTAC suite of equipment exceeds 50 pounds. To lighten the load, JTACs/FACs/FOs are forced to pick and choose from the equipment suite to best match the anticipated mission.

In a systems engineering context, the suite of equipment has both overlapping and complementary capabilities, governed by different program offices. Therefore, it can be described as both a Family of Systems and a System of Systems. The Fires and Maneuver Integration Division (FMID) of Marine Corps Combat Development Command (MCCDC) is currently working to combine several of these PoR's and UUNS into new blended PoR's. This is a challenging task.

In parallel, the Office of Naval Research (ONR) is working on new technologies whose transition target is the TACP suite of equipment. For example, there is an ongoing effort to improve azimuth pointing accuracy while reducing weight and setup time. This effort has led to a new celestial compass available for immediate integration, as well as several MicroElectroMechanical Systems (MEMS) gyrocompass technologies in the budget category 6.1-6.3 phase of Science and Technology (S&T) development. Additionally, ONR and Marine Corps Systems Command (MCSC) have complimentary programs working on developing a single imager that combines visible and IR wavelengths, with the end goal of a single optical subsystem that works 24 hours a day and can see all military lasers.

B. OBJECTIVE

The objective of this capstone project was to develop a set of trade-spaces for the integration of different capabilities into the TACP suite of equipment and provide recommendations to MCCDC, ONR, and MCSC concerning the current and future pieces of the TACP suite of equipment, concluding with a modernization plan which includes technology insertion points into specific programs.

C. DESIGN TEAM

In order to develop this capstone project, "Team Quantico" was organized and roles were assigned to each design team member in accordance with Table 1.

Table 1. Design Team Roles

Name	Role
Bryan Freeman	Team Lead, Researcher
Daniel Barb	Modeler, Editor
Mark Jackson	Modeler, Editor
Douglas Mount	Scheduler, Editor, Librarian
William Newcomb	Researcher, Editor

1. Team Leader

The team leader was responsible for setting the direction of the capstone project, assigning tasks to team members, and overall management of the capstone project.

2. Researcher

The researchers were responsible for finding information directly or indirectly related to the research topic, establishing facts, and presenting information to the team.

3. Modeler

The modelers were responsible for the discovery of mathematical relationships to physical phenomena and, performance. They turned this information into analytical models to represent realities and provide information for further analysis.

4. Scheduler

The scheduler was responsible for scheduling team meetings and events, various meetings with stakeholders, and In Process Reviews (IPRs). They also ensured the overall program schedule was updated and published prior to the IPRs.

5. Librarian

The librarian was responsible for collecting and organizing information in a logical manner such that team members can access the information on the team portal.

6. Editor

The editors were responsible for collecting the information from other team members in draft format and developing the final products so that they are complete, cohesive, and consistent. The editor then posted the final products on the team portal.

D. STAKEHOLDERS

The current required capability needs are projected to impact several different entities during the several different program life cycle phases. These entities are defined to be stakeholders and are listed within Table 2 and Table 3. For each stakeholder, specific concerns are presented to define how the stakeholder will interact with the TACP suite. Active stakeholders interact with TACP suite while it is deployed in the battlefield. Passive stakeholders interact with the TACP suite during all other times of non-deployment.

1. Active Stakeholders and Concerns

Table 2. TAC-SLM Active Stakeholders and Concerns

Stakeholders	Concerns
USMC User Community	• System must meet operational effectiveness requirements • System must provide ability to detect, recognize, and identify military and civilian equipment and personnel • System must provide the ability to provide target location information accurate enough to permit engagement by indirect fires and air assets, including unguided and precision guided weapons • System must be capable of being carried by a single Marine along with his other mission equipment • System must meet operational suitability requirements
Maintainers	• System must be maintainable
Allied Forces	• System must be interoperable with Strikelink
Local Non-Combatants	• System must be accurate to prevent increased battlefield danger • System must have a minimal environmental footprint

2. Passive Stakeholders and Concerns

Table 3. JTAC-SLM Passive Stakeholders and Concerns

Stakeholders	Concerns
MCSC	• System must be developed and fielded within cost, performance and schedule
Marine Corps Operational Test and Evaluation Activity (MCOTEA)	• System must be testable, and able to meet Measures of Performance (MOPs) and Measures of Effectiveness (MOEs)
CD&I/MCCDC	• System must fulfill functions defined in requirements documentation
Logisticians	• System must be supportable • System must be transportable • System must have minimal logistics footprint
Contractors	• System must be manufacturable with common practices • System performance must achievable
U.S. Citizens	• System must have a minimal lifecycle cost • System must have minimal environmental impact upon disposal • System must be effective and reduce U.S. and Coalition casualties

3. Project Specific Stakeholder Roles and Concerns

The JTAC-SLM capstone project interacted directly with the requirements developer (CD&I/MCCDC), the material developer (MCSC), the S&T developer (ONR), and the USMC end users. The specific personnel are listed in Table 4.

Table 4. JTAC-SLM Project Specific Stakeholder Roles and Concerns

Stakeholder	Title	Roles and Concerns
MCSC	Product Manager, Fire Support Systems (PdM FSS)	Role: Responsible for acquisition and life cycle management of fire support equipment. Concern: Wants to understand what requirements are being developed, what is currently available, and the current state of S&T development.
CD&I/MCCDC	Fires and Maneuver Integration Division – Naval Surface Fire Support (NSFS) Capabilities Integration Officer	Role: Responsible for developing requirements for current and future elements of the TACP suite. Concern: Wants to understand current state of technology, direction of S&T development, and MCSC modernization plans.
ONR	Expeditionary Maneuver Warfare and Combating Terrorism (Code 30) Fires Project Officer	Role: Responsible for aligning S&T development with CD&I/MCCDC Marine Air Ground Task Force (MAGTF) Capability Gaps and Science and Technology Objectives (STOs), and developing S&T solutions to meet those needs. Concern: Wants to understand current gaps, future Concept of Operations (CONOPS) and requirements, and Program Manager (PM) modernization

Stakeholder	Title	Roles and Concerns
		plans.
Active Duty USMC Users	FOs, FACs, JTACs, and NGFS	Role: Provide user feedback on system attributes and priorities. Concern: Wants a system that best matches the attributes required to accomplish the mission.

E. RESEARCH QUESTIONS

The primary research questions, as determined by the team, were as follows:

- What are the current requirements for the individual pieces of equipment in the TACP suite of equipment?
- What are the key performance requirements for the individual pieces of equipment in the TACP suite of equipment?
- What are acceptable areas of trade-off between the key performance requirements?
- What are the interrelationships between the key performance requirements?
- What would potential systems "look like" while varying certain key performance requirements within the trade space?
- What S&T efforts, ongoing and planned, can be utilized to realize the potential systems?
- How can these systems be realized utilizing a TRMP?

The secondary research questions, as determined by the team, were as follows:

- What are the functions that the TACP users are expected to perform with the TACP suite of equipment?

- What are the areas of overlap or conflict within the TACP suite of equipment and the TACP user functions?
- What are the risks associated with developing the potential systems?

F. ENGINEERING PROCESS

The JTAC-SLM capstone project was divided into three phases, with the output products of each phase coinciding with the two IPRs, the final report, and the final presentation. The three phases were the Research Phase, the AoA Phase, and the Technology Roadmap and Modernization Phase. While these phases had distinct products and were dependent upon one another, the work in each phase began before the previous phase concluded.

The three-phased approach described for the capstone project process follows the typical Systems Engineering process utilized during acquisition of systems. Since this capstone project fits in the pre-Milestone-A Material Solution Analysis Phase of Department of Defense (DoD) Acquisition and did not produce actual hardware, it can be best described as the left part of the Systems Engineering Vee Model [2], therefore being reduced to a simple waterfall model. The overarching phases of the JTAC-SLM capstone project, as well as the products and connections to subsequent phases, are shown in Figure 1.

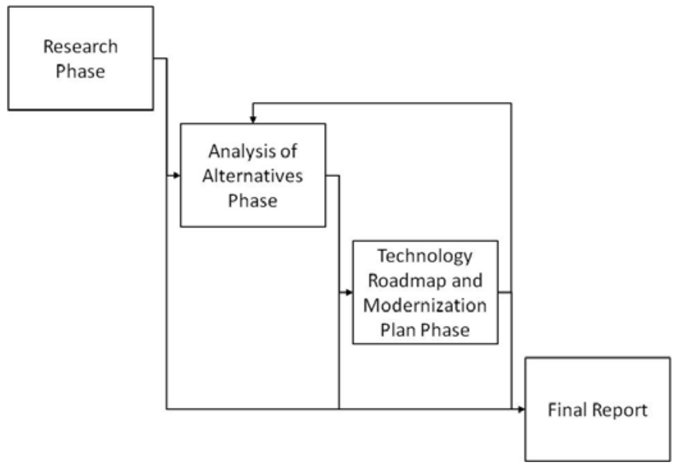

Figure 1. Top Level JTAC-SLM Project Phases

The Research Phase is shown in Figure 2.

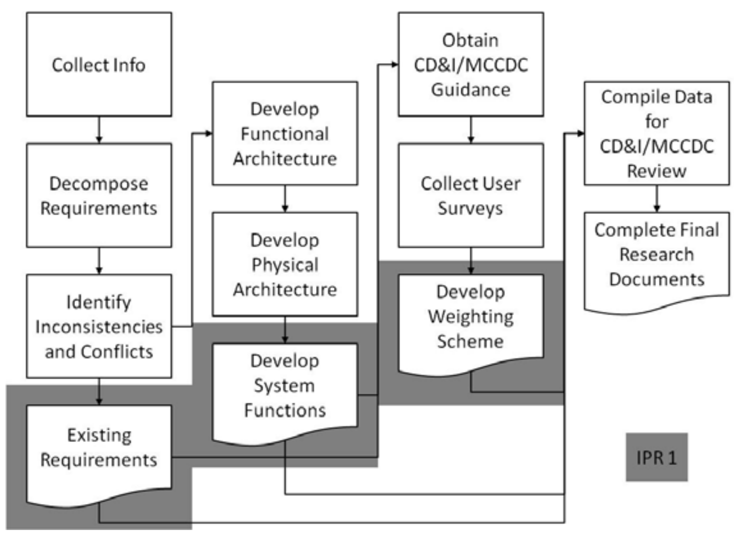

Figure 2. Research Phase Systems Engineering Flow Chart

The Analysis of Alternatives Phase is shown in Figure 3.

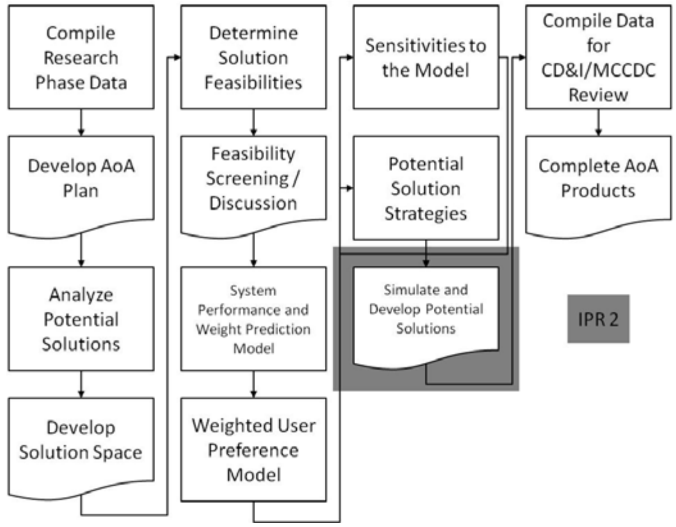

Figure 3. Analysis of Alternatives Phase Flow Chart

The Technology Roadmap and Modernization Phase is shown in Figure 4.

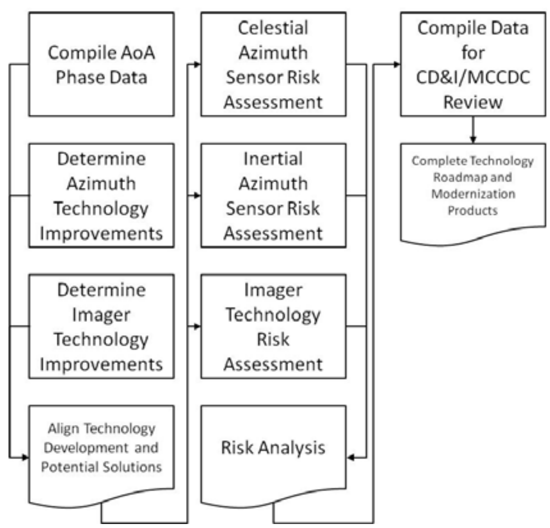

Figure 4. Technology Roadmap and Modernization Phase Flow Chart

G. SYSTEMS ENGINEERING TOOLS SUMMARY

The Systems Engineering, Analysis, and Documentation Tools that were utilized throughout this capstone project are summarized in Table 5.

Table 5. Summary of Tools

Tool Type	Use	Tool Name
Systems Engineering	Systems Engineering Analysis and Documentation	Vitech CORE
	Graphics	Microsoft Office Power Point
Analysis	General Analysis	Microsoft Office Excel
	Scientific Simulation	matlab
	Scientific Simulation	MathCad
Documentation	Reporting	Microsoft Office Word
	Presentations	Microsoft Office Power Point

H. ASSUMPTIONS AND CONSTRAINTS

1. Assumptions

The following assumptions were made in the research and analysis:

- The Department of the Army, specifically the Army Night Vision Electronic Systems Directorate (NVESD), is the world renowned expert on imaging systems. The target recognition range equations utilized in (the project model) were based upon the equations from the very sophisticated Army NVESDs Thermal and Image Processing (NVThermIP) model and Solid State Camera and Image Processing (SSCamIP) model. Therefore the focus was on obtaining information from Army Night Vision and not from other United States (U.S.) military sources or countries.

- Based upon some preliminary analysis, the Common Laser Ranger Finder Integrated Capability (CLRF-IC) was used as the baseline / starting point for the capstone project as this was the most modern and recent information available. All the rangefinder, imager, and other component weights were done by adjusting off of the CLRF-IC.
- Similarly, the laser designator module was based upon the JTAC-LTD designator system, a very recently fielded laser designator.
- The Army NVESD NVThermIP and SSCamIP models are very sophisticated and require expertise to utilize properly. Naturally, this requires funding to acquire this expertise, a luxury not available for this project. The model utilized was developed with the pro-bono assistance of NVESD but are not nearly as sophisticated as NVThermIP or SSCamIP. The results from this study should be validated by NVESD prior to making any major program decisions.
- There are other assumptions in the model that drove the findings. The process by which we obtained our findings is the key take-a-way from this capstone project and not necessarily the results of the modeling efforts.

2. Constraints

The following constraints were made in our research and analysis:

- A linear model was used to perform our simulations as opposed to a utility model (i.e. non-linear). A utility model would have provided additional resolution and insight; however it was not possible given the duration of the capstone project.

- Research was restricted to the U.S. military organizations due to the sensitivity of information available from other countries.
- The lack of additional information on new technologies limited our ability to accurately forecast the technology trends.

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II. PROBLEM DEFINITION/STATEMENT

A. STAKEHOLDER'S PRIMITIVE NEED

The primitive need for USMC FOs, FACs, and JTACs is to locate and recognize potential targets and “hand them off” for engagement by artillery, mortars, rockets, Naval gunnery, or airpower. In order to successfully accomplish this need, the users need to be maneuverable throughout the battlefield, which is often impeded by the weight of the equipment required to perform the mission task. Maintaining equipment effectiveness and minimizing overall system weight is essential to ensuring mission success and fulfilling the primitive need of the USMC JTAC community.

B. PROCESS TO ESTABLISH NEED

The process to establish the primitive need began with a Statement of Issue and Concern from USMC MAGTF Fires Operational Advisory Group (OAG) [3]. The focus was on communication, situational awareness, target location, weight, and interoperability for the dismounted JTAC. The JTAC-SLM capstone project focused on two of the five concerns and allocated the two concerns to several key performance requirements within the TACP suite of equipment. This list of key requirements was summarized to the CD&I/MCCDC stakeholder for this capstone project to ensure that the primitive need was being addressed.

C. BOUND AND SCOPE

Fire support coordination within the USMC has the following tasks: [3]

- Supporting forces in contact
- Supporting the commander’s concept of operation
- Integrating fire support with the scheme of maneuver
- Sustaining fire support

Coordination up and down the chain is accomplished via the Fire Support Coordination Centers (FSCCs), which exist at the Battalion, Regimental, and Division levels. The FSCCs coordinate fires at the appropriate level, up to and including coordination with Naval Gunfire (NGF) and with other U.S. forces aircraft. Once coordination is accomplished, the final handoff and coordination occurs directly between the supporting arms element and the firing platform. The supporting arms elements have functions according to the type of support they are responsible for controlling.

The TACP is responsible for directing and controlling CAS. The TACP includes three FACs who are also trained as JTACs. One of these three FACs is the Air Officer (AirO), and the other two FACs work under his direction. The TACP also includes four radio operators. The TACP's operate at the Regimental and Battalion level.

Artillery and mortar fires are directed by the artillery FO teams, which are organic to the firing battery of the supporting battalion [4]. Each team includes an observer liaison chief (also a FO) and three additional FO's. Each FO heads a Forward Observer Team which includes a Fire Support Man and two radio operators. The team supports a Company.

The NSFS is coordinated via the NGF Liaison Team, led by the Naval Gunfire Liaison Officer (NGLO), a NGF Chief, two Shore Fire Control Party men, and three radio operators [4]. These teams are organic to both the Regiment and Battalion.

The missions of these three supporting arms elements are very similar; therefore individuals are often cross-trained. For example, a FAC may also be a JTAC and a FO [4]. Additionally, the equipment utilized by all three supporting arms elements is also very similar, with the largest differences being the communications equipment. As shown in Figure 5 the observation, location, and marking equipment for the supporting arms elements has considerable overlap.

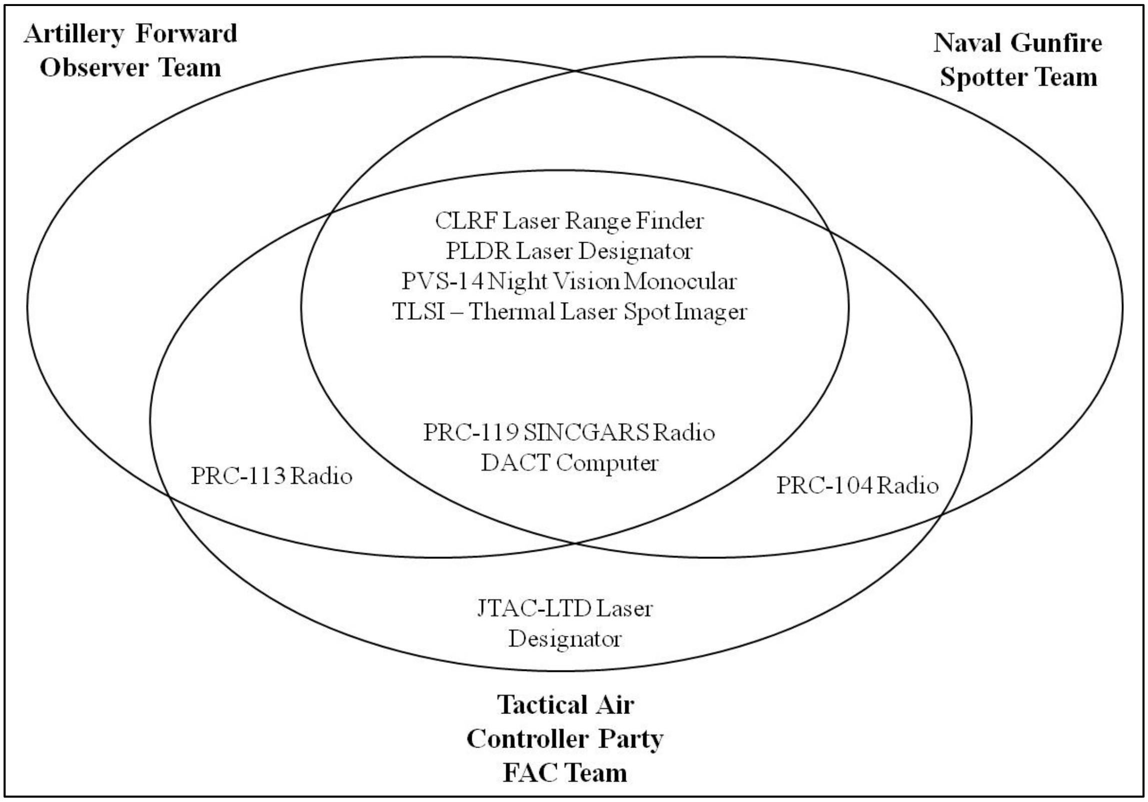

Figure 5. Overlap of Equipment

The management of the requirements and equipment for the supporting arms elements is split between the Command, Control, Communications, and Computers (C4), and the targeting systems. At MCSC, the C4 equipment is managed by PM MAGTF C4, while the targeting equipment is managed by PM Armor and Fire Support Systems (AFSS). This division is logical in that the radios used by the supporting arms elements are but a small portion of the overall radio users, and the communications up and down the MAGTF must touch systems outside USMC control, such as the Naval Fire Control System (NFCS), and are sometimes jointly managed such as the Advanced Field Artillery Tactical Data System (AFATDS). This is accomplished via voice or utilizing the Digital Automated Communication Terminal (DACT) computer running the Strikelink software suite.

However, much of the targeting and observation equipment is unique to the supporting arms mission, with the exception of the laser pointers. There are currently two types of laser pointers fielded that enable the supporting arms elements to mark targets and to call them to the attention of troops on the ground as well as aircraft. These markers operate in the visible region (Green Beam III) for unaided eyes in twilight and on bright nights or in urban environments, near IR markers, Infrared Zoom Laser Illuminator Designator (IZLID) family, for marking targets that are invisible to the naked eye but visible to image intensifying equipment. The laser marking mission is not unique to the supporting arms community and the laser marking equipment is fielded to all infantry units. The laser pointers are managed by PM Infantry Weapon Systems at MCSC and are relatively small in physical size and were thus not included as part of this capstone project. The JTAC-LTD, procured in Fiscal Year (FY) 11 under an UUNS, also includes an IR pointer.

The JTAC-SLM capstone project focuses on the observation and targeting functions shared by the JTAC user community, while other functions are outside consideration of this capstone project. While the suite of equipment is targeted toward the JTAC/FAC users, it is clear that this equipment is also used by NGFS and FO users [4]. Therefore the needs of those users are also considered as part of this capstone project.

D. REQUIREMENTS

1. Initial Requirements

As stated in the objective, the requirements were initially identified by researching the known measurable and testable requirements from various existing components of the TACP suite of equipment system and performance specifications. The requirements were reviewed from the suite of equipment which lead to a few tradable key performance requirements, which were further researched and aligned with ongoing USMC procurement and S&T efforts. A summary of the initial requirements is shown in Table 6.

Table 6. Initial Requirements

	Requirements	Description
ALL	Mission Profile	
	Duration	Operational time
	Number of Operations	Operational usage
	Weight	
	Base	Weight of unit
	Full	Weight including protective case
	Size	Unit dimensions
	Startup Time	Operational start up time
	Battery Life	Operational battery life (Hot/Cold ambient temp)
	"Climate and Terrain"	
	Operating Temperature	Operational temperature
	Storage Temperature	Temperatures stored in
	Communicate	Communicate data interface from laser designator
RANGEFINDERS (Range Includes Designators)	Detect/Recognize/ID Target Range	
	Day	Distance that operator has ability to see the reflected laser energy of a 1.064 micron laser on North American Treaty Organization (NATO) target
	Night	Distance that operator has ability to see the reflected laser energy of a 1.064 micron laser on NATO target
	Conditions	Atmospheric conditions
	Self Location	
	Accuracy	Location error distance
	Time	Time to location
	Target Location	
	Range	
	NATO	Distance for recognizing a NATO target
	Hilux	Distance for recognizing vehicle target
	Person	Distance for recognizing person target
	FOV	Field of view magnification
	Azimuth	
	Accuracy	Azimuth error distance
	Time	Time to determine azimuth location

	Requirements	Description
	Conditions	Ambient Conditions
	Vertical Angle	
	Accuracy	Vertical angular error
DESIGNATORS AND POINTERS	Target Marking	
	Energy Output	Laser energy
	Range	Range for targeting item
	Beam Divergence	Angular beam divergence
	Bore Sight Error	Angular sight error
	Duration	Time laser operates
	Duty Cycle	Laser duty cycle
	Target Size	Target size at range
LASER IMAGERS	Laser Imaging	
	Wavelength	Laser wavelength
	Range	
	Day	Distance daylight
	Night	Distance nightlight

2. Requirements Analysis

Upon completion of the initial requirements analysis, seven key performance requirements were identified. The seven key performance requirements were divided into one non-functional requirement and six functional requirements. The non-functional requirement (weight) was influenced by all of the functional requirements using predetermined relationships within the model. Even though the complete list of requirements was reduced to just seven key performance requirements, inconsistencies existed across the requirements documents leading to the CD&I/MCCDC project stakeholder resolving these requirements.

It was discovered that the laser spot imaging (day and night) requirements did not add additional weight due to the fact that the capability could be accomplished simply by adding different filters to the day and night vision optics. These were then eliminated from further consideration and that reduced the number of key performance requirements for the capstone project to five. The final five key performance functional and non-functional requirements are shown in Table 7.

Table 7. Key Functional and Non-Functional Performance Requirements

Requirement	Threshold	Objective
Functional:		
Recognition Range (Day)	3,000 meters	5,000 meters
Recognition Range (Night)	900 meters	2,500 meters
Target Location Error	25 meters	0 meters
Designation Range	2,000 meters	5,000 meters
Non-Functional:		
Weight	8.00 lbs	2.75 lbs

3. Measures of Effectiveness/Measures of Performance

As part of the research phase, an analysis of the requirements of the existing TACP suite of equipment was conducted. As part of the analysis a dendritic functional relationship of the key performance requirements was associated to Marine Corps Tasks (MCT), Critical Operational Issues (COIs), Measures of Performance (MOP), and Measures of Effectiveness (MOE). A COI is a key operational issue that must be examined to determine the systems capability to perform its' mission. The purpose of an MOP is to provide a quantifiable measure for a distinct feature of the system. The MOE corresponds to an accomplishment of mission objectives and achievement of desired results [5]. All COIs are linked to a MCT, which are provided within the Marine Corps Task List (MCTL). The analysis is shown in Figure 6 as the JTAC-SLM Dendritic Functional Relationship.

MCT	COI	MOE Level	MOP Level		Verfication Method
All COI trace to each MCT					
MCT 1.3.3.3.2 Conduct Aviation Operations From Expeditionary Shore-Based Sites MCT 3.1.2 Decide/Conduct Target Development, Validation, Nomination, and Prioritization MCT 3.2.3.1.1 Conduct Close Air Support (CAS) MCT 3.2.5.3 Control Naval Surface Fire Support (NSFS) MCT 3.2.7.2 Control Indirect Fires					
	COI 1 - Is the system effective in allowing the user to recognize targets?				
		MOE 1.1 - Target recognition			Test
			MOP 1.1.1 - Target recognition range day		Test
			MOP 1.1.2 - Target recognition range night		Test
	COI 2 - Is the system effective at marking targets for handoff to aircraft and weapon systems?				
		MOE 2.1 Target designation range for laser guided weapons			Analysis
			MOP 2.1.1 Target designation range		Test
		MOE 2.2 Target designation range for laser spot trackers			Analysis
			MOP 2.2.1 Target designation range		Test
	COI 3 - Is the system effective at locating targets for precision guided munitions?				
		MOE 3.1 Target location error			Analysis
			MOP 3.1.1 Azimuth error		Test
			MOP 3.1.2 Rangefinder error		Test
			MOP 3.1.3 Self Location (GPS) error		Test
	COI 4 - Is the system suitable for use by dismounted Marine users?				
		MOS 4.1 System weight			Demonstrate

Figure 6. JTAC-SLM Dendritic Functional Relationship

This capstone project is scoped to only consider items from the MCTL applicable to observation and targeting capabilities shared by the FACs, FOs, and NGFSs. In particular the MOPs and MOEs are limited to the functionality provided by the TACP suite of equipment required to accomplish their missions.

E. STAKEHOLDER ANALYSIS

A stakeholder analysis was performed by developing an influence matrix, followed by an influence-interest grid. These products drove the necessary information gathering, meetings, and briefings with the stakeholders.

1. Stakeholder Influence Analysis

A stakeholder analysis was performed beginning with the development of an Influence Matrix, shown in Table 8. In this table, “D” stands for Direct, meaning that particular stakeholder has a direct influence over that aspect of the system and “I” stands for Indirect. The stoplight colors indicate how much power that stakeholder has over that aspect.

Since this capstone project focused on the pre-Milestone A (Material Solution Analysis) Phase of system development, some stakeholders influence and power progressed as the project proceeded. For example, MCOTEA can have a heavy influence on system production, as an unfavorable report will jeopardize the program. Although MCOTEA did not provide input in the development of this capstone project, they are represented by proxy by CD&I/MCCDC and MCSC. An interesting fact of life is the influence contractors have over funding due to influence within the Legislative Branch.

While ONR doesn’t appear to have a large role, there is S&T development required to make the mid-term and far-term systems successful. ONR’s role on the near-term system (CLRF-IC) is complete since they developed the lightweight, low cost, first generation celestial compass (azimuth sensor) with S&T funds and transitioned this product to MCSC and Industry.

Table 8. Stakeholder Influence Matrix

Stakeholder	Impact on				
	Requirements	**System Design**	**System Production**	**System Acceptance**	**Funding**
MCSC FSS		D	I		
CD&I/MCCDC	D	I			D
MCOTEA	I	I		I	
ONR		I			D
User Community	I	I		D	I
Maintainers	I	I			
Allied Forces	I				
Local Non-Combatants	I				
Logisticians	I	I		I	
Contractors			D		I
U.S. Citizens	I		I		I

The capstone project utilized the Power versus Interest Grid adopted from Eden and Ackerman, shown in Figure 7, for the top five stakeholders [6]. The results are shown in Figure 8. This analysis was used to determine how stakeholders interacted.

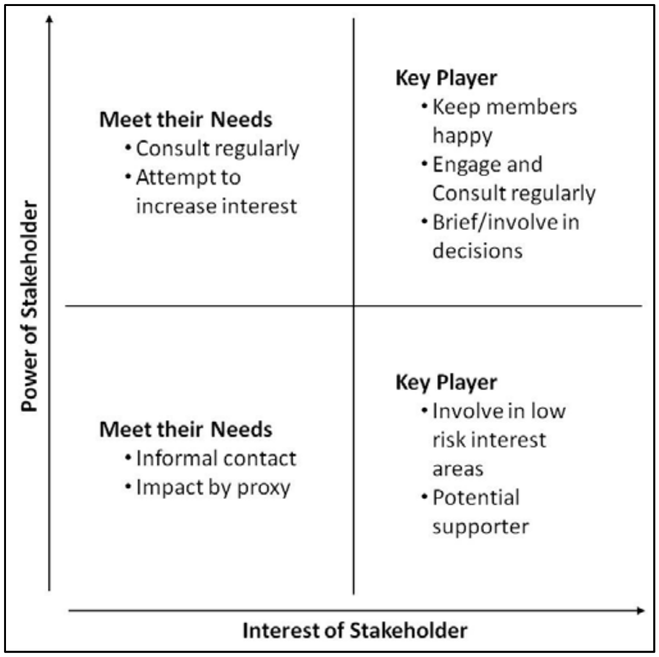

Figure 7. Stakeholder Power versus Interest Matrix Definition, After [6]

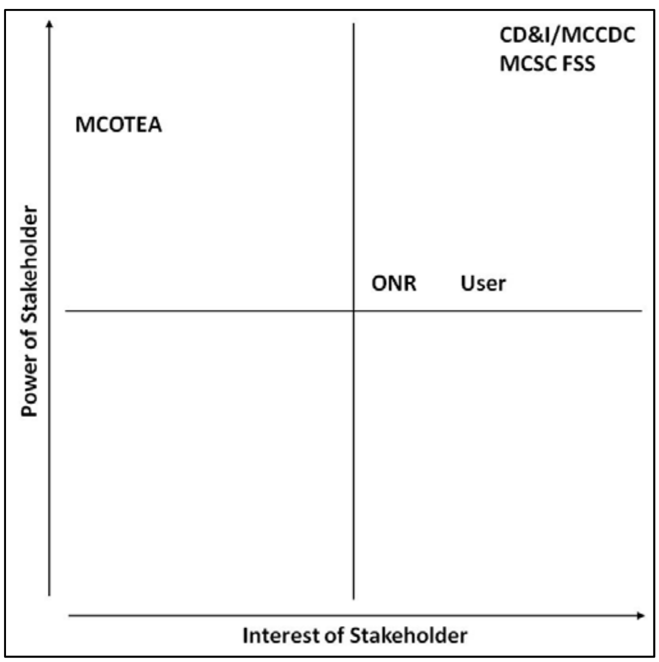

Figure 8. Stakeholder Power versus Interest Matrix

2. Stakeholder Meetings

A brief summary of all the meetings held with different stakeholders is shown in Table 9.

Table 9. Stakeholder Meeting Summary

Stakeholder	Meeting Summary
MCSC	Discussed overall requirements that were being identified by the project and the current state of S&T development.
CD&I/MCCDC	Discussed plans of USMC from requirements side and received guidance on PMP plans. Received requirements documents.
MCSC	Discussed current program plans and began user survey discussions.
CD&I/MCCDC	Discussed tradable requirements, deconflicted requirements, received final trade space within requirements.
ONR	Received information about ongoing S&T programs that support TACP Suite of Equipment as well as ONR's future S&T plans.
MCSC	Provided user surveys for dissemination to active duty USMC FOs/FACs/JTACs.
MSCS/Active Duty USMC Users	Received completed user surveys as well as feedback from SME.
CD&I/MCCDC	Provided user survey analysis and user preference weights.
MCSC	Provided TRMP for edit and concurrence.
ONR	Provided TRMP for their future reference.

F. VALUE HIERARCHY

To generate the value hierarchy, which is what was used to evaluate the modeling and simulation results, the following sequence was used. First, requirements were researched from multiple USMC programs and were consolidated. Once completed, subject matter experts were utilized to ensure the key performance requirements were acceptable for the process, and user input was sought and utilized to evaluate the relative importance of each requirement.

One of the major concerns the CD&I/MCCDC stakeholder and the MCSC FSS stakeholder stressed during this process was to not place too much emphasis on current operations, as they are mostly urban combat with very short range requirements. Thus, the focus of the capstone project was increased to include compartmentalized warfare, which consists of mountains and valleys with distinct small areas to consider with substantially longer ranges. The focus of the capstone project was an important factor in both what systems were researched as well as the parameters within the value hierarchy and system model.

The value hierarchy was constructed based upon the results from the surveys that were received from a group of users with different experiences utilizing the equipment being addressed within the capstone project. The surveys were based upon a -9, -3, -1, 0, 1, 3, 9 weighting system for the comparisons so that the further a response was from neutral, the more impact it has on the overall score of the survey.

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III. DESIGN AND ANALYSIS

A. GENERAL APPROACH

As mentioned in previous sections, the JTAC-SLM capstone project was divided into three phases, with the output products of each phase coinciding with the two IPRs, the final report, and the final presentation. The three phases were the Research Phase, the AoA Phase, and the Technology Roadmap Phase. While these phases had distinct products and were dependent upon one another, the work in each phase began before the previous phase concluded. The sequence of events and schedule followed during the capstone project is shown in Figure 9. The details of this plan are presented in the following sections.

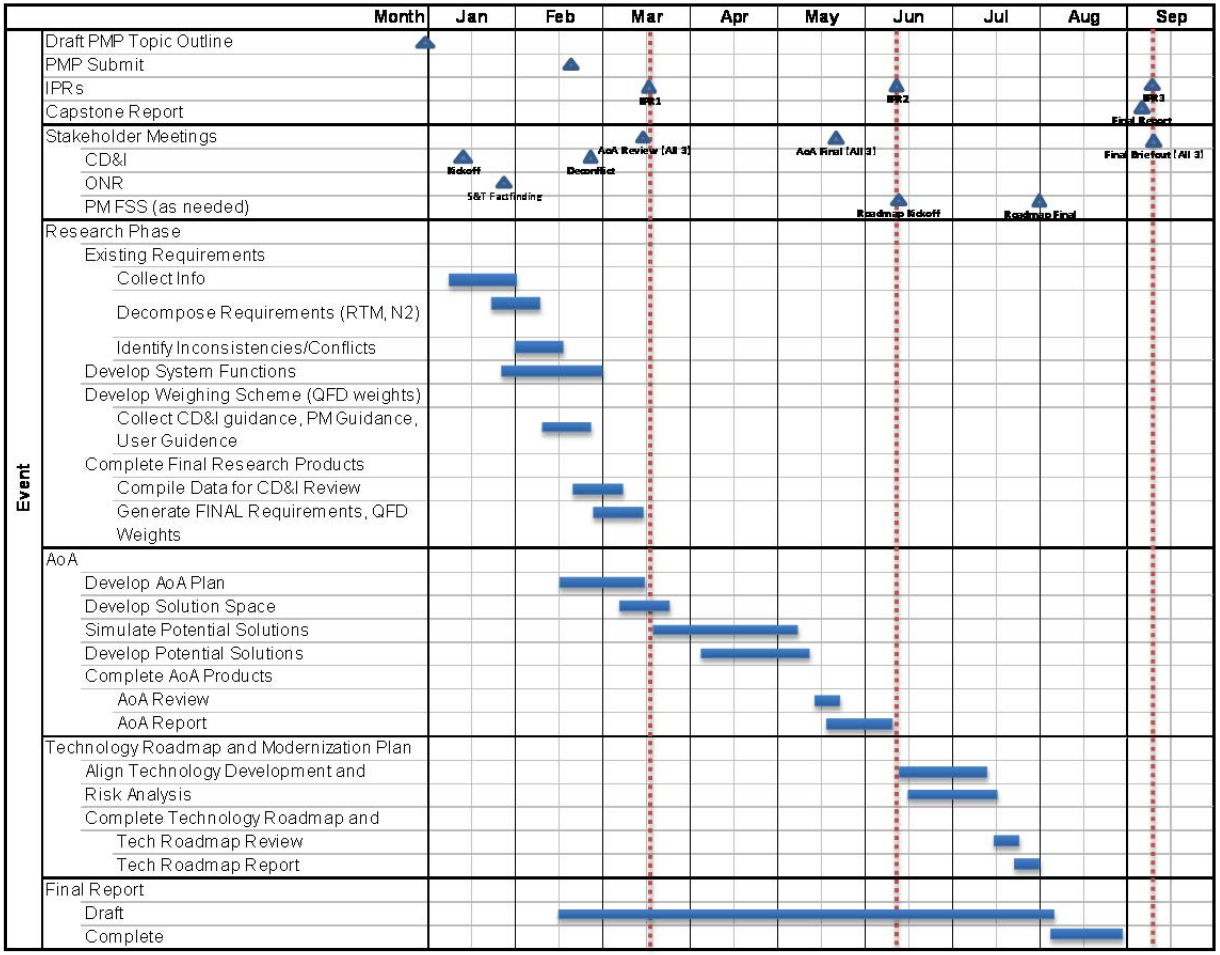

Figure 9. JTAC-SLM 2012 Schedule

B. SOLUTION PHASES

1. Research Phase

The Research Phase consisted of the collection and evaluation of the existing requirements, gathering of information from the Project Specific Stakeholders (Table 4), and the development of the importance of the requirements to the equipment users. The specific components of the Research Phase and the activities completed within them are summarized below.

a. Existing Requirements

In order to complete the JTAC-SLM capstone project and develop potential future systems, it was important to fully understand current requirements, the functions that led to the requirements, and the nominal mission profiles for which the requirements are based. Without this information, any development of futures systems may not be able to be compared to current systems or may not meet user needs.

The process used to develop system requirements was described previously in section II D, and the requirements themselves can be found in Table 7.

The sequence of events for the Existing Requirements task was as follows:

- Collect documentation on existing systems and systems in the planning phases
- Determine the key requirements and the functions that led to them
- Develop a Requirements Traceability Matrix (RTM) for these requirements, including the nominal mission profiles
- Develop an N-squared (N2) diagram for the systems
- Determine potential inconsistencies and trade space
- Present the list of key requirements, RTM, and N2 to CD&I/MCCDC and MCSC to get guidance and direction

- Document final RTM, N2, and key requirement bounds

b. *Develop System Functions*

The information collected during the previous tasks enabled the development of the functions that the supporting arms users require from their equipment. The functions were found in the documentation that led to the development of the existing systems. There was a concern that these may also have conflicts, but this wasn't the case.

The sequence of events for the Develop System Functions task was as follows:

- Collect documentation on existing systems and systems in the planning phases
- Analyze the documentation and determine the functions from the requirements documents
- Determine the key functions that the equipment was required to perform for the users
- Develop a Functional Flow Block Diagram (FFBD) for these functions
- Determine potential inconsistencies
- Document final functions in text and FFBD format

(1) Functional Architecture. A FFBD was created to better understand how each major operational activity of the system interacted with other activities. Generic terms were used so as not to be solution specific or accidently eliminate potentially superior equipment for consideration.

The FFBD in Figure 10 clearly shows the major functions that must happen within the JTAC-SLM. First, Surveillance must be conducted in order to determine if any potential targets are available. During Surveillance, a target is recognized through the Target Recognition function. At this point several things can happen, but the two that affect our system are that the target can be located through the Locate function to get that targets position in order to transfer that location data on to supporting fire (usually artillery or aircraft) or it can be pointed at through Target Designation function if there is already aircraft equipped with laser spot trackers and/or laser guided weapons on station. The last stand alone function of the system is the Laser Spot Imaging function, which would be used to confirm that something else is pointing at the same target.

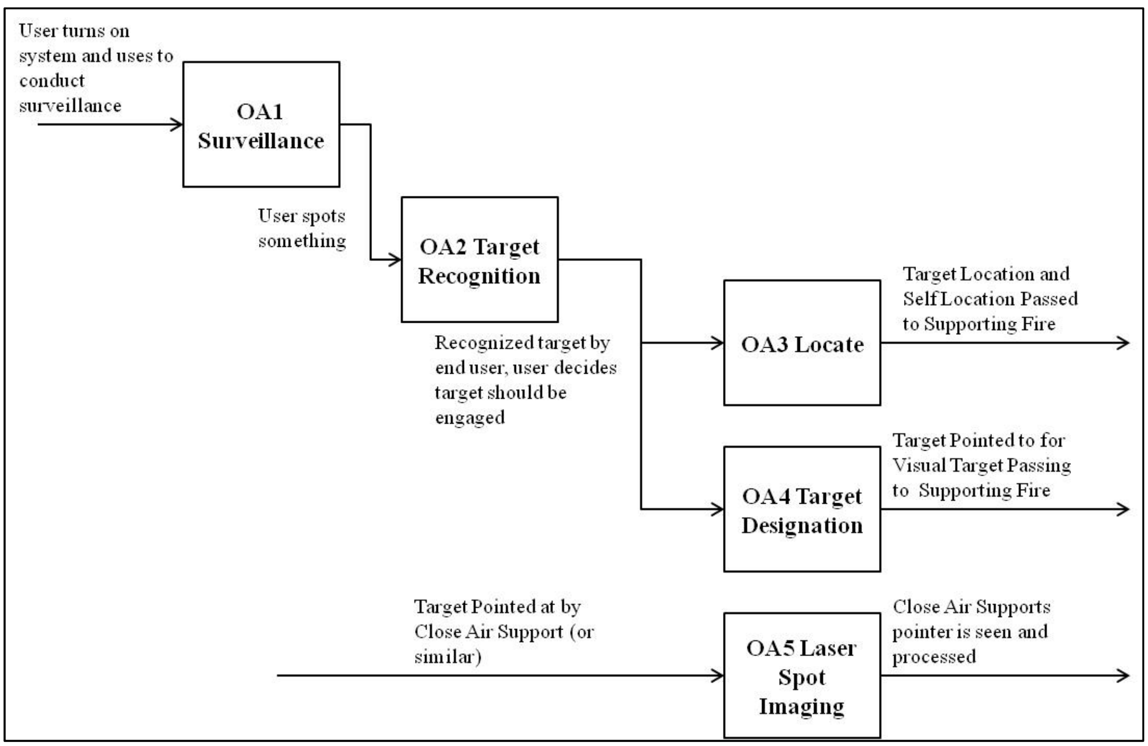

Figure 10. Functional Flow Block Diagram

(2) Process used to create Physical Architecture. Once a functional architecture was established, creating a physical architecture was an extension of what subsystems would be required to achieve each function, then comparing that to existing N2 Diagrams to ensure completeness. In order to create an architecture that was unbiased, specific subsystems were not identified as future technologies may make a

specific named technology incorrect. An example of this is using the term “self-locator” instead of Global Positioning System (GPS), which actually isn't the complete solution for self-location since it will not function in a GPS denied environment. Because the N2 Diagram was based on the currently fielded systems, it includes specific program names, which are not carried over into the physical architecture.

The N2 Diagram depicted in Figure 11 shows the currently fielded systems and how each system within the Family of Systems (FoS) interoperates. From this, it is apparent that most subsystems are standalone with some interaction with the thermal imager/laser spot imager, the TLSI. The only exception to this is CLRF, which interacts with the DAGR handheld GPS receiver to generate target coordinates.

		Receiver									
		Internal GPS	Range Finder	Designator Component	Day Camera Component	Night Vision Component	Azimuth Component	Laser Spot Imager	Display	Aircraft LSI	D-DACT (StrikeLink)
Source	Internal GPS	Serial Port									
	Range Finder		Vendor Choice								
	Designator Component			Vendor Choice						PRF and PIM Codes	
	Day Camera Component				Vendor Choice						
	Night Vision Component					Vendor Choice					
	Azimuth Component						Vendor Choice				
	Laser Spot Imager							PRF and PIM Codes			
	Display								Vendor Choice		
	Aircraft LSI									Laser Reflection	
	D-DACT (StrikeLink)	PLGR+96 ICD Message 5029									Serial Port

Figure 11. N2 Diagram

The Functional to Physical Architecture depicted in Figure 12 shows the trace between functions and actual architecture components. Starting with the Operational Activity of Surveillance and Target Recognition, this required a user interface and optical subsystem components. The user actively does these activities on the current systems with the help of equipment, but this architecture is not solution specific. Operational Activity Locate is composed of two parts, self-location and enemy location, which is found using a distance finding device and compass. Based on the N2 Diagram, the distance finding device must interoperate with the optical subsystem. Operational Activity Target Designation requires a subsystem that points at its target, which must also interoperate with the optical subsystems. Lastly, Operational Activity Laser Spot Imaging must be able to detect what is being pointed at by other units, such as close air support. This is accomplished through the optical subsystems as well. The Other physical subsystems support subsystems A1–A6.

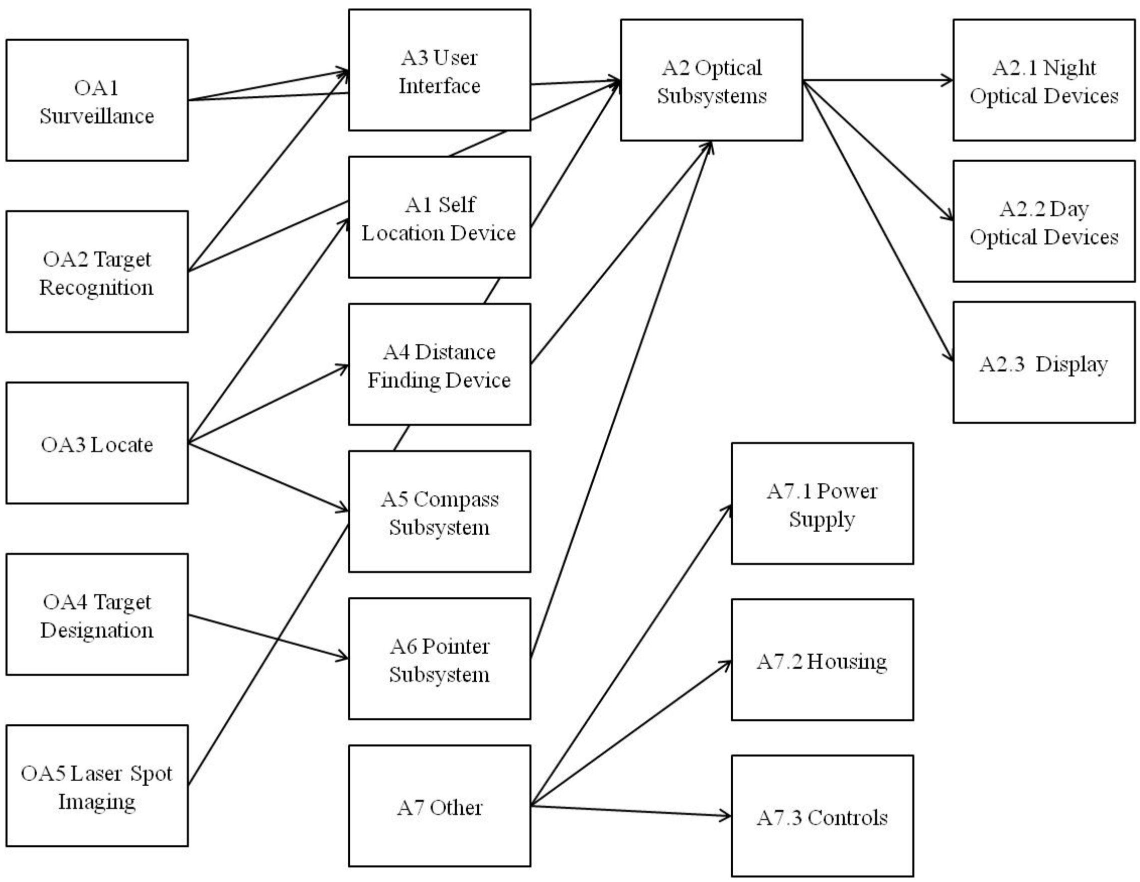

Figure 12. Functional Physical Architecture

c. Develop Weighting Scheme

Upon the conclusion of the Existing Requirements task, the importance of each of the different key requirements as they related to each other needed to be understood. Given that lightening the MAGTF is part of the 2nd priorities set in the Commandant's Planning Guidance [7], component weight was estimated to be a high priority for the user; however, how high of a priority was unknown.

To further define the importance of each of the five key requirements within the relevant systems, a user survey was created. This survey was provided to several active duty Marines with various theatre experience in order to gain additional insight into the importance of the requirements. An example of the survey can be found in Appendix A.

A total of 28 responses from users were received, of which only 27 contained complete responses. The responses were compiled and analyzed in order to determine the overall ranks and weights of the five requirements. The results of the analysis showed that only two of the requirements contributed significantly to the weight structure.

The requirement that was determined to be the most important to users of the system was Target Location Error (TLE), which was 67% higher than system weight, the next highest requirement. Although this result was unexpected, it was confirmed during sidebar discussions that were held at a conference [8] where many users and developers meet to discuss the future of the field. During the discussion, several experienced users of the system confirmed the findings giving the rationale that having the ability to accurately determine the locations of enemies and fire upon them is critical in avoiding friendly fire and fratricide. Lower TLE also meets the Commandant's "Lighten the MAGTF" priority, because low TLE means that fewer munitions will have to be expended to meet mission requirements. If only one munition is saved over the lifetime of the MAGTF equipment suite, there will still be a total weight savings to the MAGTF. Naturally, a low TLE will reduce munitions expended significantly, with a very large weight savings to the MAGTF.

The requirement that was determined to be the second most important to users of the system was Weight. The high ranking of this requirement was expected given the current priority paradigm of the Commandant and attitudes of many of the users. The remaining three requirements rounded out the analysis with each of them having similar weights.

A complete list of weights for each of the requirements can be seen in Figure 13. The weights of each of the requirements were critical to the capstone project and were heavily utilized within the modeling portion of the capstone project.

Criteria	Criteria	1 Weight	2 Recognition Range (Day)	3 Recognition Range (Night)	4 Target Location Error	5 Designation Range	Weights
Weight	1	1.000	3.111	2.259	0.600	1.704	0.249
Recognition Range (Day)	2	0.321	1.000	0.726	0.193	0.548	0.080
Recognition Range (Night)	3	0.443	1.377	1.000	0.266	0.754	0.110
Target Location Error	4	1.667	5.185	3.765	1.000	2.840	0.415
Designation Range	5	0.587	1.826	1.326	0.352	1.000	0.146
		0.249	0.080	0.110	0.415	0.146	1.000

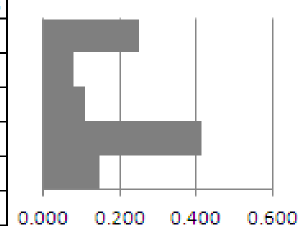

Figure 13. User Preference Weights

The sequence of events for the Develop Weighting Scheme task was as follows:

- Collect priorities from the Project Specific Stakeholders and other SME's as guided by the Stakeholders
- Compile the list of priorities in a matrix

- Present the prioritized list to the Project Specific Stakeholders. The MCCDC Stakeholder will be the tie breaker as they are tasked to develop future requirements

d. Complete Final Research Documents

All of the documents developed during the Research Phase were compiled and presented for a final review. The CD&I/MCCDC stakeholders own the USMC requirements; therefore the CD&I/MCCDC stakeholder for this capstone project had the final say for the products of this phase. The data included all the products of the previous tasks, including the RTM, N2 diagram, and the weighting scheme.

The sequence of events for the Complete Final Research Documents task was as follows:

- Collect and finalize the RTM, the N2 matrix, the weighing scheme, and any other products developed during this phase
- Present the products for a final review to MCCDC for approval

2. Analysis of Alternatives Phase

The AoA Phase consisted of determining the interactions between the requirements and predicting system performance based on these interactions. Typically, an AoA would be performed by an independent body and usually takes many months to perform. However, this AoA was conducted on an expedited schedule to allow the Stakeholders to better understand the trade space between requirements and permit informed decisions on how to proceed with the development of the TACP suite. The major products of the AoA phase were a modeling and analysis tool that allowed for the interaction of the requirements trades and prediction of system Size, Weight, and Power (SWaP) given certain requirements and technologies. The specific components of the AoA Phase and the activities completed within them are described in the following section.

a. Develop AoA Plan

Prior to undertaking this phase of the capstone project, a "plan" needed to be developed to ensure that all activities of this phase were to be conducted in the proper order and utilizing the proper information. Due to the importance of this phase of the capstone project, receiving feedback from the Stakeholders prior to starting was essential to ensure success of the capstone project.

The sequence of events for the Develop AoA Plan task was as follows:

- Utilize information gathered in the Existing Requirements task as input into the AoA plan
- Develop AoA plan

b. Develop Solution Space

Considerations had to be made prior to the development of potential solutions in order to remove systems that, for one reason or another, were unacceptable. To accomplish this task, requirements developed during the Research Phase, which included input from the Project Specific Stakeholders, were considered. Potential solutions that were deemed "non-starters" were identified and eliminated while being careful to not potentially eliminate a potential solution too early in the process. Much of this effort took place during the development of the project model and development of potential solutions. The solution space was determined by narrowing to systems that only fell within the trade space of the five key requirements as well as contained characteristics that were all physically possible. The FFBD and the requirements were major inputs to this effort.

The sequence of events for the Develop Solution Space task was as follows:

- Determine alternative methods to satisfy the supporting arms functions other than reuse, replacement, upgrade, or enhancement of the existing equipment

- Collaborate with the Project Specific Stakeholders to determine the solution space

c. *Feasibility Screening/Discussion*

Prior to beginning the modeling effort, the feasibility of the near, mid, and long term systems was researched. The feasibility drew from the information received from ONR and industry and includes the availability of technology, cost of components, and technical risk. While a complete analysis of technology development efforts and recommendations is described in the Modernization Plan part of this report, some of this work was done up front before modeling commenced. This was a recursive effort.

The near-term program is the CLRF-IC, which is currently in the Technology Development phase. The mid-term system is Engineering Change Proposal (ECPs) to CLRF-IC and also the new JTAC-SLM program. JTAC-SLM hasn't been initiated, but is in the planning phase [9] and S&T efforts to support it have begun at ONR. The far-term system is ECPs to the JTAC-SLM or may even be a new, yet to be developed program.

First, a discussion of the currently fielded man-portable targeting device is in order. The CLRF base system is a direct view binocular with an integrated eye safe laser range finder, a digital magnetic compass to determine target direction, an interface to a Defense Advanced GPS Receiver (DAGR) GPS receiver. The Digital Magnetic Compass (DMC) is the weakest part of the system; it has significant issues which will be discussed further in the Technology Roadmap section. For night vision, the system requires the addition of a PVS-14 monocular night vision scope, which is attached to one eyepiece via an adapter. The CLRF does not have the ability to see laser energy.

The CLRF-IC program will represent a significant improvement over the currently fielded CLRF. It will have an integrated GPS, a celestial compass in addition to a DMC. The DMC will be used for backup because, naturally, a celestial compass won't work when it's cloudy. However, CLRF-IC will most likely utilize an image intensifier or a Long Wave Infrared (LWIR) imager, and neither of these technologies is capable of seeing designator laser energy. To meet this need, either a Mid Wave Infrared (MWIR) or Short Wave Infrared (SWIR) imager is required, and both currently require cool-down time, are power hungry, and are cost prohibitive.

GPS Selective Availability Anti-Spoofing Module (SAASM) cards are far smaller and lower power than they were even a few years ago. These components will be available for CLRF-IC and all future systems.

ONR is currently developing a new inertial azimuth sensor in support of CLRF-IC and JTAC-SLM candidate program. While the accuracy of this sensor is unlikely to exceed the celestial compass, it will be capable of determining azimuth all the time.

A summary of these systems and the feasible technologies is shown in Table 10**.**

Table 10. Technology Feasibility Chart

		Today	Near-Term	Mid-Term	Far-Term
Function	**Component**	**CLRF**	**CLRF-IC**	**JTAC-SLM and CLRF-IC ECP's**	**JTAC-SLM ECP's or New Program**
Day Recognition	Direct View Optic	Yes	Possible		
	Indirect View Optic		Likely	Yes	Yes
Night Recognition	Image Intensifier	Clip-on	Possible		
	LWIR		Possible		
	MWIR			Likely	Yes
	SWIR			Likely	Yes
Laser Spot Imager	MWIR or SWIR		Unlikely	Yes	
Self-Location	GPS SAASM	External	Yes	Yes	Yes
Target Location (Azimuth Component)	DMC	Yes	Yes	Yes	Yes
	Celestial Compass		Yes	Yes	Yes
	Inertial Azimuth Sensor			Likely	Yes

d. Simulate and Develop Potential Solutions

The goal of this task was to develop the tools to investigate the trade space of key requirements based on the input from the prior tasks. This enabled the building of potential solutions to show the balance of system performance within acceptable bounds for the requirements. Running parallel with the simulations, solutions based on a balance of technology availability, technology performance, and requirements were developed.

The sequence of events for the Simulate and Develop Potential Solutions task was as follows:

- Develop the relationship between individual component performance and overall system performance
- Develop software tools to predict the trades between key requirements
- Develop visualization method to assist the analysis of system parameters against performance
- Collect information about technology solutions from PdM FSS and ONR
- Develop performance for individual components
- Utilize simulation tools to predict system performance based on technology
- Analyze performance and build up system based on technology solutions and output from simulations
- Present potential systems to Project Specific Stakeholders

(1) System Model. The overall model included both a system performance and weight prediction model and the weighted user preference model. Together, they provide not only the predicted system performance, but also the overall "score" based upon the predicted performance and user preferences. This is a powerful method that incorporates the voice of the user to allow for the development of systems that best match technology capabilities, requirements, and user desires.

(2) System Performance and Weight Prediction Model. The system performance model is central to the analysis of candidate systems. The model

developed for this paper was low resolution. A higher resolution model would include parametric runs of NVThermIP and SSCamIP, development of system components and architecture, materials selection, buildup of manufacturing tolerances, and the like. This is far too complex for a capstone project of this duration.

To simplify things considerably, the system model utilized a baseline system built up from market research and comparable systems. The equations of both NVThermIP and SSCamIP were utilized to increase/decrease the system recognition range off of this base system. The new lens size of this candidate system was compared to the baseline to compute the change in system weight based upon that component. The designator component was handled in a similar manner, with the assumption that designator lens sizes scale with range similarly to day and night imagers. TLE component weights were either given through market research or from information given by ONR.

Some system components were fixed based upon the known weights of these items. These were adjusted according to the timeframe (near, mid, and far-term) due to technology improvements. The notable exception is the housing weight, which was chosen to be a fixed percentage of the sum of the component weights.

(a) Baseline Data. The first step of generating the model was to determine some of the baseline data necessary to input into the model. This consisted of market research of vendors, vendor meetings, conversations with the CLRF-IC program office, and existing systems. Many vendors provided input in confidence; therefore, they could not be referenced as sources. This information was invaluable to the model as it provided baseline data that allowed the projection of future capabilities.

The majority of the information captured dealt with the expected weights of the proposed systems and system components. Other information was summarized from the research, such as certain lens diameters, but this information was only used as a reference point and not placed within the model. Once the weights of the systems from five different proposals were determined, an average weight for the system and system components was calculated. These average weights were used within the model in sections described later in this report.

A summary of the information gathered was tabulated. This information is not presented within this paper due to the proprietary information provided by vendors. The results of this analysis are presented in Table 11, which represents a rollup of all the information gathered and sufficiently sanitized to remove proprietary information so as to not violate the confidence of the vendors. Note that some manipulation had to be made in order to calculate certain averages as some systems reported weights that seemed unreasonable (i.e. extremely high or low) given other systems of the same technology.

These base weights were used as inputs to the model, which were adjusted according to the performance of the candidate system versus the base system.

Table 11. Summary of Proposed System Base Weight Analysis

Component	Weight (g)	Description of Analysis
Housing	510.32	Average of all systems
Direct View Optics (DVO)	162.00	Average with one system removed
Day Camera	131.05	Average of all systems but high standard deviation
Image Intensifier (I^2)	181.00	Average of all systems
LWIR	140.45	Average with one system removed
Eyepiece	95.30	Average with one system removed
DMC	32.89	Average of all systems but high standard deviation
Celestial	88.31	Average of all systems
Laser Range Finder (LRF) Module	84.60	Average of all systems
Electronics	152.51	Average of all systems but high standard deviation
GPS	61.16	Average of all systems
Battery	124.33	Average with one system removed
Total	**1,763.92**	

(b) Input Data Flexibility. The model permits the adjustment of many parameters, some of which are dependent upon each other, some are dependent on chosen technologies, some must be "reasonable", and some may be "tuned" using engineering logic and reasoning in order to attempt to arrive at the best result.

A summary of the key model parameters is shown in Table 12. Items shown in red are requirements of the system. Items in blue are inputs into the weight calculation. Note that the azimuth weight parameters are fixed, except for the technology improvement factor.

Table 12. Key Model Parameters

	Variable	Input or Output	Type	Description
Recognition Range Day	Range	Input	Variable	Requirement
	Target Size	Input	Fixed	Standard
	Resolution	Input	Fixed	Standard
	Technology Type	Input	Fixed	Mature technology
	Pixel Pitch	Input	Variable	Depends on Predicted State of Technology
	f/#	Input	Fixed	Fixed by mature technology
	Aperture Diameter Size	Output	Computed	Input to weight calculation
Recognition Range Night	Range	Input	Variable	Requirement
	Target Size	Input	Fixed	Standard
	Resolution	Input	Fixed	Standard
	Technology Type	Input	Fixed	Mature technology
	Pixel Pitch	Input	Variable	Depends on Technology Type and Predicted State of Technology
	f/#	Input	Fixed	Limited by Technology Choice
	Aperture Diameter Size	Output	Computed	Input to weight calculation
Designator Range	Range	Input	Variable	Requirement
	Improvement Factor	Input	Variable	Predicted based on timeframe and technology S-curve
	Aperture Diameter Size	Output	Computed	Input to weight calculation
Target Location Error	Self-Location Error (Sigma GPS)	Input	Variable	Fixed based upon available technology
	Rangefinder Error (Sigma Range)	Input	Variable	Fixed based upon available technology
	Sigma Azimuth	Input	Variable	Predicted on technology and timeframe
	Target Location Error	Output	Variable	Requirement
Weight	Weight Power	Input	Variable	Used in optics weight calculation - derived from Johns Hopkins University Applied Physics Laboratory (APL) report and set to 2.5. Acceptable values are 2-3
	System Total Weight	Output	Variable	Function of all input parameters and fixed system weights

(c) Night Vision Imager Technology Parameters. Some of the night vision technology parameters are key drivers to overall aperture size, and thus overall subsystem weight. They are the technology chosen, the f/#, and the pixel size. A summary of reasonable numbers is shown in Table 13 and Table 14, which were given by Army NVESD [10].

Table 13. Night Vision Projected Pixel Sizes

IR Technology		Near-Term	Mid-Term	Far-Term
	SWIR	12μm	6μm	2.2μm
	MWIR	12μm	8μm	6μm
	LWIR	17μm	12μm	8μm

Table 14. Acceptable f/#numbers

IR Technology		f/# Range	Rationale
	SWIR	Near f/1 (Night) Up to f/12 (Day)	Night - Inadequate Illumination Day - Adequate light
	MWIR	f/3-f/4	Sensor Noise proportional to f/#
	LWIR	Near f/1	Sensor Noise proportional to (f/#) squared

(d) Technology Improvement Factors. In addition to new technologies that are predicted to become available in time for the mid-term and long term systems discussed in the Feasibility Screening section, some more mature technologies will continue to improve in performance and decrease in weight. To predict the amount of improvement over time, the technology S-Curve method was utilized. This method was developed by Genrich Altshuller in the former Soviet Union in the 1950's, and is still relevant today [11].

This method is less well known than the more famous "Moore's Law", which predicts that the transistor count on computer chips doubles every two years. However, Murrae Bowden showed that Moore's law is actually a specific case of S-Curves because as each Photoresist technology reaches its performance limit, there is a new technology right behind it that is adopted and takes over where the old technology left off [12]. A typical S-Curve is shown in Figure 14.

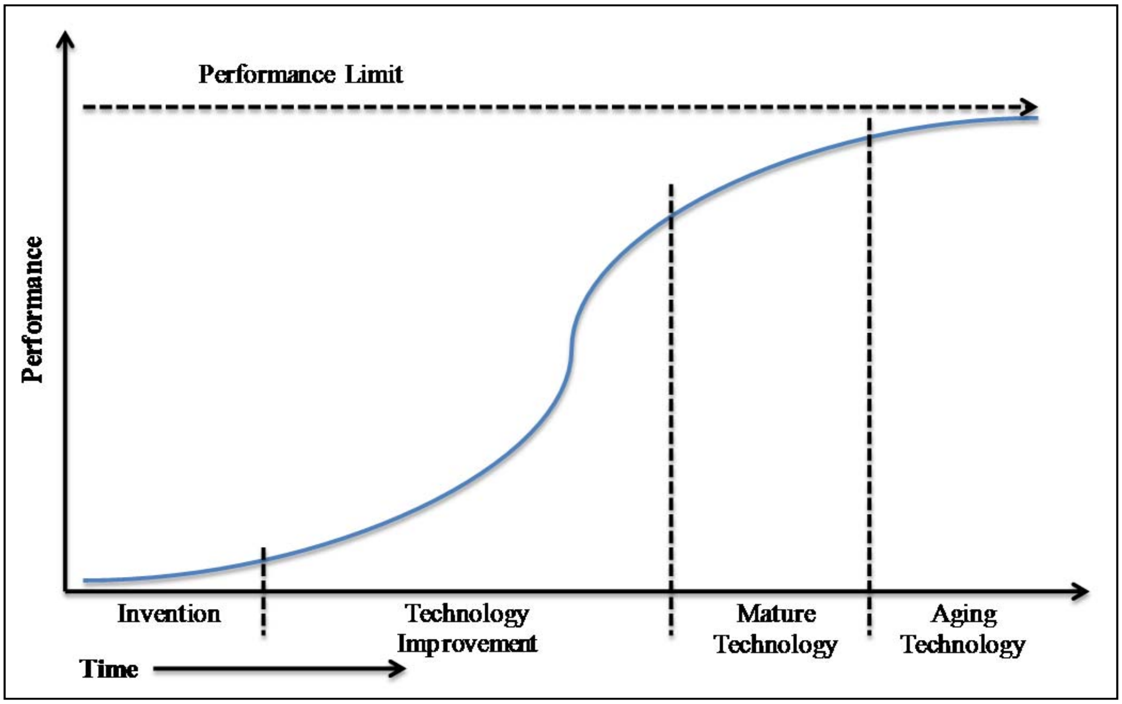

Figure 14. Typical S-Curve, From [12]

Each maturing technology was analyzed to determine its current place on the S-Curve and then predictions were made as to what "performance factor" should be applied for future applications of the technology. A list of each technology improvement factor, as well as the rationale for each, is shown in Table 15.

Table 15. Technology Improvement Factors

		Near-Term	Mid-Term	Long Term	Rationale
Improvement Factors	DMC	1.00	1.00	1.00	Very mature technology
	Celestial Compass	1.00	0.67	0.50	Still in Technology Improvement Phase - First Fielded 2011
	MEMS Inertial Azimuth Sensor	-	1.00	0.67	First Fielding in mid-term
	Designator	1.00	0.67	0.50	Newer diode-pumped mono block technology first fielding in 2011
	Electronics	1.00	0.80	0.72	Continuing to improve, but already mature
	GPS	1.00	0.80	0.72	Continuing to improve, but already mature
	Battery	1.00	0.80	0.72	Continuing to improve, but already mature

(e) Technology Time Frame and System Attributes. The first two sections of the model are areas that allow the user of the model to select different inputs. Step one of the model allows the user to select which type of system is being simulated. This information has no impact on the rest of the model. Selections of "FY14" indicated a system in the near-term, selections of "FY19" indicated a system in the mid-term, and selections of "FY24" indicated a system in the far-term. The inclusion of this piece is for record keeping of the type of system being examined. An example of this step of the model can be found in Figure 15. Notice the blue highlight within the attribute column. This highlight represents a field that can be manipulated by the user. This same methodology is used throughout the rest of the model as well. The range of values that are able to selected are provided within the field labeled "Range" within the model, as seen from the figure. This too is standard throughout the model.

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY14	N/A	FY14, FY19, FY24

Figure 15. Step 1 of the System Performance and Weight Prediction Model

Step two of the model allows the user to select the values for three of the five key requirements for the system being simulated. For each of the key requirements, a slider bar is utilized to vary the value within the allowed range. This information is used in later steps of the model. Note that the model allows for value outside the range of interest. This was done for flexibility of the model in case changes had to be made to any of the requirement ranges or to analyze a potential solution beyond the desired attributes. This was a standard practice throughout the model as long as the values were feasible. An example of this step of the model can be found in Figure 16.

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000		0 to 10,000 m
Recognition Range - Night (m)	900		0 to 10,000 m
Designation Range (m)	2,000		0 to 10,000 m

Figure 16. Step 2 of the System Performance and Weight Prediction Model

(f) Aperture Size Calculation. Steps three and five of the model are similar steps that utilize the same methodology to calculate aperture size from a given recognition range. The only difference between the two steps is that one is used to calculate the aperture size of the day lens and the other is used for the night lens. An example of step three of the model is provided in Figure 17. Note that a figure for step five was not provided to eliminate redundancy.

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	-		
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.77	N/A	Calculated
Pixel Angular Size (urads)	191.67	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Calculated

Figure 17. Step 3 of the System Performance and Weight Prediction Model

This portion of the model has several different attributes that are selected by the user and several that are calculated using information within the model. "Recognition Range" was selected within step two of the model and carried over to this part of the model. "Target Size" was taken from the different requirements documents that were reviewed within the Research Phase of the capstone project. "Technology Type" was varied from system to system in order to determine the optimal technology given the desired capability. "Resolution", "Pixel Pitch", and "f/#" were all values that were determined through consultation with the Army NVESD. Note that the options for the "f/#" change within the model based upon which technology type is selected – these were chosen based on Table 14. "f/# Hard Code" provides the same information as "f/#", but the capability was added to allow the user to enter a value outside of the "f/#" range. This was done for experimentation purposes only and was not utilized during the final simulations. "Wavelength" is the wavelength of the light that is utilized from the different technology types. These wavelengths are standard knowledge from any physics text book. Note that the options for "Wavelength" change based upon the technology type selected. "Target Angular Size", "Pixel Angular Size", "Q", and "Aperture Diameter Size" are all calculated attributes that were derived using Army NVESD's NVThermIP and SSCamIP models [10]. These models are the standard models used by the U.S. Government to determine different attributes of these types of technologies. The equations for each of these attributes are detailed in Equation 1, Equation 2, Equation 3, and Equation 4.

$$Target\ Angular\ Size\ (mrads) = \frac{1000 \times Target\ Size\ (m)}{Recognition\ Range\ (m)}$$

Equation 1: Target Angular Size in millirads

$$Pixel\ Angular\ Size\ (\mu rads) = \frac{1000 \times Target\ Angular\ Size\ (mrads)}{2 \times Resolution}$$

Equation 2: Pixel Angular Size in microrads

$$Q = \frac{{}^{f}/_{\#} \times Wavelength\ (\mu m)}{Pixel\ Pitch\ (\mu m)}$$

Equation 3: Factor known as "Q"

$$Aperature\ Diameter\ (mm) = \frac{1000 \times Wavelength\ (\mu m)}{Q \times Pixel\ Angular\ Size\ (\mu rads)}$$

Equation 4: Aperture Diameter in millimeters

(g) Aperture Weight Calculation. As with the previous section, steps four and six of the model are also similar steps that utilize the same methodology to calculate aperture weight from the previously determined aperture diameter. The only difference between the two steps is that one is used to calculate the aperture weight of the day lens and the other is used for the night lens. An example of step four of the model is provided in Figure 18. Note that a figure for step six was not provided to eliminate redundancy.

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Given
Weight of System Optics (g)	86.77	N/A	Calculated

Figure 18. Step 4 of the System Performance and Weight Prediction Model

This portion of the model has several different attributes which are selected by the user and several that are calculated using information within the model. "Weight of Base Camera", "Weight of Base System", and "Aperture Diameter Base Size" are pieces of information that were determined from the baseline data previously mentioned. "Weight Power" is a coefficient that was determined by researching the effects of aperture size and weight. A paper produced by Johns Hopkins University [13] demonstrated that the coefficient for this variable fell somewhere between two and three by correlating different weights of different systems to the size of the aperture. The decision was made to take the average of the two numbers and two and half was used consistently for the entire capstone project. "Weight of Base Optics" was derived from taking the difference between the weight of the base camera and the weight of the base system. The equation for this attribute can be found in Equation 5.

$$Weight\ of\ Base\ Optics\ (g) = Weightof\ Base\ System\ (g) - Weight\ of\ Base\ Camera\ (g)$$

Equation 5: Weight of Base Optics in grams

"Aperture Diameter Size" is the diameter size calculated previously in steps three and five. The diameter calculated in step three is used within step four and the diameter calculated in step five is used within step six. "Weight of System Optics" references the Rayleigh Criterion [14], which represents the fundamental upper limit of optical performance given aperture size. This is also called the 'diffraction limit'. The equation used to calculate the optics weight is given within Equation 6.

$$Weight\ of\ System\ Optics\ (g) = Weight\ of\ Base\ Optics\ (g) \times \left(\frac{Aperature\ Diameter\ Size\ (mm)}{Aperature\ Diameter\ Base\ Size\ (mm)}\right)^{Weight\ Power}$$

Equation 6: Weight of System Optics in grams

(h) Target Location Error Performance Calculation. Step seven of the model calculates the TLE of the system. TLE is the error that the system gives on a two-dimensional axis for a given target. This error is calculated using simple trigonometric principles of lengths, angles, and ratios. The better the system is at locating a target, the smaller the error needs to be. An example of step seven of the model can be found in Figure 19.

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	5.0		1 to 20 mil
Theta (rad)	0.0049	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	19.63	N/A	Calculated
Sigma X (m)	20.26	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	15.36	N/A	Calculated

Figure 19. Step 7 of the System Performance and Weight Prediction Model

This portion of the model has several different attributes which are selected by the user and several that are calculated using information within the model. "Sigma GPS", "Sigma Range", and "Theta" are pieces of information that are current standards within industry. Sigma GPS and Sigma range were consistent throughout the entire modeling effort while theta decreased as technologies improved. These factors were based off of information gathered from ONR [15]. Theta in radians is a simple conversion from theta in mils. The equation to convert theta is given in Equation 7.

$$Theta\ (rad) = \frac{Theta\ (mil) \times 2\pi}{6400}$$

Equation 7: Theta in radians

"Recognition Range" is the range at which the location error is calculated. This attribute was kept consistent throughout all simulations in order to keep the systems comparable and was assigned a value based upon CLRF-IC requirements. "Sigma Azimuth", "Sigma X", "Sigma Y", and "Target Location Error" are all calculations that are based off of input from ONR. The equations for these attributes can be found in Equation 8, Equation 9, Equation 10, and Equation 11.

$$Sigma\ Azmuth\ (m) = Recognition\ Range\ (m) \times Sine[Theta\ (rad)]$$

Equation 8: Sigma Azmuth in meters

$$Sigma\ X\ (m) = \sqrt{Sigma\ GPS\ (m)^2 + Sigma\ Azmuth\ (m)^2}$$

Equation 9: Sigma X in meters

$$Sigma\ Y\ (m) = \sqrt{Sigma\ GPS\ (m)^2 + Sigma\ Range\ (m)^2}$$

Equation 10: Sigma Y in meters

$$Sigma\ Azmuth\ (m) = 0.5887 \times [Sigma\ X\ (m) + Sigma\ Y(m)]$$

Equation 11: Target Location Error in meters

(i) Target Location Error Weight Calculation. Step eight of the model calculates the weight of the pieces that determine the TLE of the system. This portion of the model is a simple calculation that uses baseline data and adds the weight to the system if the component is present. The model does allow for technological improvements to the different components as was shown in Table 15. An example of step eight of the model can be found in Figure 20.

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	1.00		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	88.3	N/A	Calculated
MicroElectroMechanical Systems Included	No	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	0.0	N/A	Calculated

Figure 20. Step 8 of the System Performance and Weight Prediction Model

"Digital Magnetic Compass (DMC) Included", "Celestial Included", and "MicroElectroMechanical Systems Included" are "Yes" or "No" questions that allows the user to determine if any of these three components are present within the system. The DMC and the celestial system are fielded technologies that are proven. Therefore, these two systems were included on all systems as they provide a unique capability that does not have a replacement. The MEMS inertial azimuth sensor is a system that is still in development and therefore was only included on future systems. "DMC Improvement Factor", "Celestial Improvement Factor", and "MEMS Improvement Factor" are attributes that allow the user to decide whether the technology will have any improvements in the future with regards to weight. These were chosen in accordance with Table 15. The attributes allow the user to select a factor between zero and one and this factor is then multiplied against the current weight in order to obtain a reduced weight based upon predicted technology maturity. The DMC has been fielded for many years and no expected improvements are planned for the system. The factor for this component remained at one (i.e. no weight reduction) for all simulated systems. The celestial system, although a proven system, is still relatively new to the field and this factor was adjusted in future systems. The MEMS is a new system and future improvements were also expected for this system. “DMC Base Weight”, “Celestial Base Weight”, and “MEMS Base Weight” are all attributes that are based off of either current technology weights or developmental technology weights. The DMC and celestial system weights were taken from the baseline data. The MEMS inertial azimuth sensor weight was taken from ONR, the developer of the device. “DMC Weight”, “Celestial Weight”, and “MEMS Weight” are the products of the respective base weights and improvement factors for the same technologies.

(j) Designator Weight Calculation. Step nine of the model calculates the weight of the designator depending upon whether a designator is included or not within the simulated system. An example of the model for step nine is included within Figure 21.

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	1.00		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	500.0	N/A	Calculated
Designation Range (m)	2,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	23.0	N/A	Calculated

Figure 21. Step 9 of the System Performance and Weight Prediction Model

“Designator Included” is a “Yes” or “No” question that lets the user determine whether a designator is present within the simulated system. The designator was included for all simulated systems since this is the desire of MCCDC/CD&I [16]. “Designator Improvement Factor” is an improvement factor that was adjusted for future systems based on the technology being fielded, but relatively new. “Designator Module Base Weight” is the base weight of the entire module that was provided by one of the vendors, who wishes to remain anonymous. This base weight was not manipulated throughout the simulation as the improvement factor accounts for any weight changes. “Designator Module Weight” is the combination of the base weight and the improvement factor. “Designation Range” is one of the attributes that the user sets within step two of the model. "Weight Power” is the same attribute that was discussed within steps four and six of the model. “Designator Optics Base Size” is an attribute that stayed the same throughout the entire simulation and was based off of currently fielded technologies. “Designator Optics Base Weight” was calculated using the same methodology used in Equation 6. In order to calculate a base weight for the designator optics, the base weight for the night recognition optics had to be utilized. This assumption was made due to the lack of information on the designator and the fact that designator optics scale the same as observation optics. “Designation Base Range” is the range of the current fielded system from which the optics base size was taken. “Designator Optics Weight” uses the same methodology shown in Equation 6, but uses ranges instead. The formula used to calculate the designator optics weight can be found in Equation 12.

$$
\begin{aligned}
&Designator\ Optics\ Weight\ (g) \\
&\qquad = Designator\ Optics\ Base\ Weight\ (g) \\
&\qquad \times \left(\frac{Designation\ Range\ (m)}{Designation\ Base\ Range\ (m)}\right)^{Weight\ Power}
\end{aligned}
$$

Equation 12: Designator Optics Weight in grams

(k) Additional Weight Calculation. In order to calculate the complete weight of an entire system, step ten of the model was added to include all of the additional components that are required for a system. The methodology used here is the same methodology used within step eight of the model. For each of the components, an improvement factor was estimated given the technology status, base weights were calculated from the baseline data, and a final weight of each component was calculated based upon the improvement factor and base weight of each respective system. The components this methodology was used for were the LRF, the electronics of the system, the GPS, and the battery. An example of step ten within the model can be found in Figure 22.

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	1.00		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	84.6	N/A	Calculated
Electronics Improvement Factor	1.00		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	152.5	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	1.00		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	61.2	N/A	Calculated
Battery Improvement Factor	1.00		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	124.3	N/A	Calculated

Figure 22. Step 10 of the System Performance and Weight Prediction Model

(l) Weight Roll-up Calculation. Step eleven of the model is the roll-up of all of the previously calculated weights within the model as well as the addition of three additional weights. The three additional weights introduced in this step are the "Night Imager Cooler Weight", the "Eyepiece Weight", and the "Housing Weight". An example of step eleven of the model can be found in Figure 23.

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	86.8	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	0.0	N/A	Given
Night Imager Lens Weight (g)	262.6	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	88.3	N/A	Given
MEMS Weight (g)	0.0	N/A	Given
Designator Module Weight (g)	500.0	N/A	Given
Designator Optics Weight (g)	23.0	N/A	Given
LRF Weight (g)	84.6	N/A	Given
Electronics Weight (g)	152.5	N/A	Given
GPS Weight (g)	61.2	N/A	Given
Battery Weight (g)	124.3	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	650.9	N/A	Calculated
Total Weight (g)	2,252.3	N/A	Calculated
Total Weight (lbs)	4.97	N/A	Calculated

Figure 23. Step 11 of the System Performance and Weight Prediction Model

The night imager cooler weight was a given weight dependent upon the type of technology that was used for the night imager. If the night imager uses SWIR or MWIR technology, a cooler is required in order to make the technology work. A standard weight was found for the type of cooler that would be required for these types of technologies from Ricor, a provider of cryogenic coolers [17]. If the night imager uses LWIR, no cooler is required and the weight was zero. This weight is a standard weight that did not change throughout the entire simulation.

The addition of the eyepiece weight was added for completeness and the information for the weight of this system was determined during the baseline data analysis. This weight was a standard weight that did not change throughout the entire simulation.

The final additional weight that was added was for the housing of the system. The total percent weight of the housing from the baseline data was used because as technologies improve, they may require less space and therefore less housing. This meant that the housing size would fluctuate at an unknown rate based upon the system being simulated. The baseline housing percentage weight was applied to all systems once the remaining components could be summed and compared to the baseline systems.

Once all of the weights were calculated, the total weight of the system was calculated and converted into pounds. This was done due to the fact that the key requirement for weight was given in pounds.

(3) Weighted User Preference Model. The secondary model, the weighted user preference model, was used to take all of the five key requirements and place them within the preference scheme. This was simply done by comparing the calculated or selected value for each of the requirements and comparing them to the requirements laid out by CD&I/MCCDC. If the calculated key requirement only achieved the threshold requirement, a score of zero was assigned. If the calculated key requirement achieved the objective requirement, a score of one was assigned. If the key requirement fell between the threshold and objective values for the requirement, linear

regression was used to calculate the assigned value between zero and one. No extra penalty or reward was assigned for systems that failed to meet the threshold or achieved beyond the objective. To account for this, only systems that had all five key requirements fall within the threshold and objectives values for each requirement were considered. Once the "normalized" score for each key requirement was assigned, the weights for each requirement were applied and the scores were summed up to give an overall preference rating. This rating was then used to compare systems in order to determine the most "preferred" system. An example of this portion of the model can be seen in Figure 24.

Overall Preference		0.3038
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	4.97
	Normalized Preference	0.5780
	Calculated Weight	0.2489
	Weighted Preference	0.1439
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	3,000
	Normalized Preference	0.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0000
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	900
	Normalized Preference	0.0000
	Calculated Weight	0.1102
	Weighted Preference	0.0000
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	15
	Normalized Preference	0.3856
	Calculated Weight	0.4148
	Weighted Preference	0.1599
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	2,000
	Normalized Preference	0.0000
	Calculated Weight	0.1461
	Weighted Preference	0.0000

Figure 24. Weighted User Preference Model

(4) Potential Solutions Strategy. Once the model had been completed, selected input variables were varied (including key requirements and other attributes) in the model in order to produce systems that fell within the solution space. Systems were developed for three different time frames: near-term, mid-term, and far-

term. A summary of the findings can be found in Table 16, Table 17 and Table 18. Each of the simulations with all variables is presented in Appendix B.

(a) Near-Term Systems. CLRF-IC is the official program of record under development. Cost constraints force CLRF-IC to omit the designator and utilize LWIR technology for night target recognition. The Marines will have to continue to rely on JTAC-LTD for designation and IR pointing functions.

The near-term systems were developed upon the CLRF-IC system with one change. CLRF-IC doesn't have a designator, and without these components the system weight is artificially low which gives a relatively high system score. Since this system would not meet the minimum system requirements, it is not included in this analysis.

The summary of the considered near-term systems is shown in Table 16. The yellow color is to draw attention to how that system differed from the system above it in the table. System 1 is the CLRF-IC with the addition of a laser designator that meets the minimum designation range.

System 2 increases the night recognition range to the maximum amount possible while still meeting the 8 pound requirement. Because of the high weight with a relatively low increase in night recognition range combined with the user preference weights, this system's score is lower than System 1. The root cause is the increase in optics weight for the LWIR night vision components.

System 3 replaces the LWIR imager in System 1 with SWIR technology. This system has a lower score than System 1, but this is a bit unfair, since SWIR gives the ability to see designator laser spots, which was not considered in our model because MWIR consistently outperforms both LWIR and SWIR. Therefore, SWIR technology was not investigated further as a near-term technology.

System 4 replaces the SWIR imager with an MWIR imager. This maintains the ability to see laser spots as in SWIR, but has a higher score than either the SWIR or baseline System 1. This was worthy of further investigation.

System 5 increases the day recognition range to the maximum considered (5000m). This further increases the system score. The reason is that to increase the recognition range only slightly increased the day optics weight, but is more than offset by the increased score impact due to user preferences.

System 6 increases the designator range to the maximum considered (5000m). This also increases the system weight slightly, but is overcome by the increased user preference for longer designation range.

System 6.1 represents a system where night recognition is increased to the maximum considered. This increases the overall system score to the highest of the group. System 7 gives the users everything they could hope for, except for the higher system weight. Unfortunately, MWIR technology isn't affordable in the near-term, but the technology might be something to be considered in the mid-term.

Table 16. Near-Term Simulated Systems

System Number	Night Technology	Pixel Pitch (µm)	Day Recognition Range (m)	Night Recognition Range (m)	Designator Range (m)	LSI	Weight (lbs)	Score
1	LWIR	17	3,000	900	2,000	No	4.97	0.3038
2	LWIR	17	3,000	1,675	2,000	No	8.00	0.2134
3	SWIR	12	3,000	900	2,000	Yes	5.07	0.2991
4	MWIR	12	3,000	900	2,000	Yes	4.75	0.3141
5	MWIR	12	5,000	900	2,000	Yes	5.44	0.3611
6	MWIR	12	5,000	900	5,000	Yes	6.08	0.4772
6.1	MWIR	12	5,000	2,500	5,000	Yes	6.35	0.5742

(b) Mid-Term Systems. Three major improvements are seen in mid-term systems over the near-term systems. First, the pixel sizes decrease due to technological maturity and investment by industry. Second, MEMS based inertial azimuth sensors become available for the first time. Third, the accuracy of the azimuth sensor (both celestial compass and inertial azimuth sensors) improved from 5 mils to 2 mils. Additionally, there are technological improvements that lower weight of other system components, which was performed according to Table 15.

There is a danger here – there is no additional 'benefit' realized in the model for the addition of the inertial azimuth sensor, but it does increase system weight. Fortunately, this sensor is very lightweight, and the improvements to MWIR pixel pitch lower system weight significantly over the highest scoring near-term system, as will be described next.

System 7 is identical to System 6.1, with the exception of the reduction in pixel pitch, the addition of the inertial azimuth sensor, the improvements in both azimuth accuracy, and other system weigh reductions due to technological improvements (Table 15). The pixel pitch reduction has effect of lowering the night vision optics weight.

System 7.1 reduces the night recognition range to the minimum range acceptable to see if the reduction in system weight, combined with user preferences, will improve overall system score. This was not the case – although night recognition range has a lower user preference than system weight (Figure 13), the increase in weight was not large enough to overcome the increase in nighttime recognition performance. This result illustrates why system simulation including user preferences is a valuable method – it would be difficult to score the systems effectively without this tool.

System 7.2 makes the prediction that industry might be capable of reducing pixel pitch to six microns – an improvement that naturally won't be without added cost. However, this improvement only improves the system score slightly, which begs the question whether it is worthwhile to improve MWIR pixel pitch at all. System 7.3 investigates this question.

System 7.3 is exactly the same as System 6.1, except for the technological improvements. The score shows that the technological improvements dominate the pixel pitch reduction, calling into question whether investing in this improvement is worthwhile.

System 8 investigates replacing the MWIR night vision technology with SWIR. It turns out that the SWIR score is slightly lower than the MWIR score, however this score difference isn't enough to solve the debate between SWIR and MWIR as both technologies have their strengths and weaknesses. ONR is investing heavily in SWIR technology because of some of the perceived advantages of SWIR. This analysis supports ONR's decision to invest in SWIR, particular SWIR that doesn't require active cooling.

System 9 increases night recognition range beyond the requirement, to match both the maximum day recognition range and the designator maximum range. While this system is outside the requirement set, it is interesting to note that the overall system score is the highest in the mid-term set. This sets up a recommendation that CD&I/MCCDC may want to consider increasing the objective range for the next generation JTAC-SLM to 5000m if it offers operational utility.

Table 17. Mid-Term Simulated Systems

System Number	Night Technology	Pixel Pitch (μm)	Day Recognition Range (m)	Night Recognition Range (m)	Designator Range (m)	LSI	Weight (lbs)	Score
7	MWIR	8	5,000	2,500	5,000	Yes	5.65	0.7146
7.1	MWIR	8	5,000	900	5,000	Yes	5.55	0.6092
7.2	MWIR	6	5,000	2,500	5,000	Yes	5.59	0.7172
7.3	MWIR	12	5,000	2,500	5,000	Yes	5.84	0.7055
8	SWIR	6	5,000	2,500	5,000	Yes	6.32	0.6830
9	MWIR	8	5,000	5,000	5,000	Yes	6.16	0.6904

(c) Far-Term Systems. Three major improvements, based upon industry feedback and SMEs from ONR, are seen in the far-term system over the mid-term system. As before, the pixel sizes decrease and azimuth accuracy improves due to technological maturity and investment by industry. Since with the MWIR based system, the users can "have it all" – meaning that all requirements are at their maximum, there was only one system investigated. The lower pixel size has such a small impact on system weight it wasn't significant enough to even consider. Nearly all the score improvement was due to the technological maturity and azimuth accuracy improvement. Unless there is some sort of breakthrough technology that comes available in the far-term, it isn't worthwhile, performance wise, to wait for the far-term technologies in lieu of the mid-term technologies. However, cost reductions in manufacturing may make it worthwhile.

Table 18. Far-Term Simulated System

System Number	Night Technology	Pixel Pitch (μm)	Day Recognition Range (m)	Night Recognition Range (m)	Designator Range (m)	LSI	Weight (lbs)	Score
10	MWIR	6	5,000	2,500	5,000	Yes	5.09	0.7701

(5) Sensitivities to the Model.

(a) Five Preference Factors Sensitivities. A sensitivity analysis was performed on each of the five preference factors of Weight, Recognition Range (Day), Recognition Range (Night), Target Location Error, and Designation Range in order to determine the effect each one had on the various near-term, mid-term, and far-term systems. The sensitivity analysis was conducted by varying the weight of each of the five preference factors from the actual weight to a weight of one. Only one factor was adjusted at any given time. The results were then extrapolated to weights of zero for each factor. The corresponding tables and graphs below depict the results.

The sensitivity analysis for each of the five preference factors on the near, mid, and far-term systems are displayed in Table 19, Table 20, and Table 21 respectively.

Table 19. Sensitivity Analysis on Near-Term Systems

Evaluation Measure	Original Weight	Weight of 1	Alternate						
			Near 1	Near 2	Near 3	Near 4	Near 5`	Near 6	Near 6.1
Original	-	-	0.3038	0.2134	0.2991	0.3141	0.3611	0.4772	0.5742
Weight = 1	0.2489	1	0.5780	0.0002	0.5589	0.6193	0.4868	0.3664	0.3134
Rec Range (Day) = 1	0.0800	1	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000
Rec Range (Night) = 1	0.1102	1	0.0000	0.4844	0.0000	0.0000	0.0000	0.0000	1.0000
TLE = 1	0.4148	1	0.3856	0.3856	0.3856	0.3856	0.3856	0.3856	0.3856
Des Range = 1	0.1461	1	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000

Table 20. Sensitivity Analysis on Mid-Term Systems

Evaluation Measure	Original Weight	Weight of 1	Alternate					
			Mid 7	Mid 7.1	Mid 7.2	Mid 7.3	Mid 8	Mid 9
Original	-	-	0.7146	0.6092	0.7172	0.7055	0.6830	0.6904
Weight = 1	0.2489	1	0.4475	0.4667	0.4582	0.4109	0.3208	0.3504
Rec Range (Day) = 1	0.0800	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Rec Range (Night) = 1	0.1102	1	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000
TLE = 1	0.4148	1	0.6434	0.6434	0.6434	0.6434	0.6434	0.6434
Des Range = 1	0.1461	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 21. Sensitivity Analysis on Far-Term System

Evaluation Measure	Original Weight	Weight of 1	Alternate
			Far 10
Original	-	-	0.7701
Weight = 1	0.2489	1	0.5546
Rec Range (Day) = 1	0.0800	1	1.0000
Rec Range (Night) = 1	0.1102	1	1.0000
TLE = 1	0.4148	1	0.7130
Des Range = 1	0.1461	1	1.0000

(i) Weight Factor. As Weight was varied from zero to a value of one, the resulting effect was systems that had lower weights increased in score and systems that had higher weights decreased in score. This makes sense in the fact that as weight increases, a lower score is achieved within the model. If the weight factor is more heavily relied upon, that same trend is only going to be amplified. See Figure 25 for the complete results of varying Weight as a factor. The starting and ending points of any given system were determined by how heavy they originally were and how much of the other factors the systems utilized. As weight became the only factor, the systems approached the normalized value for weight (i.e. where they were located on the range of weights between two and three quarter pounds and eight pounds). As weight was removed completely, the systems approached values determined by how much of the other four factors they utilized, which varied from system to system.

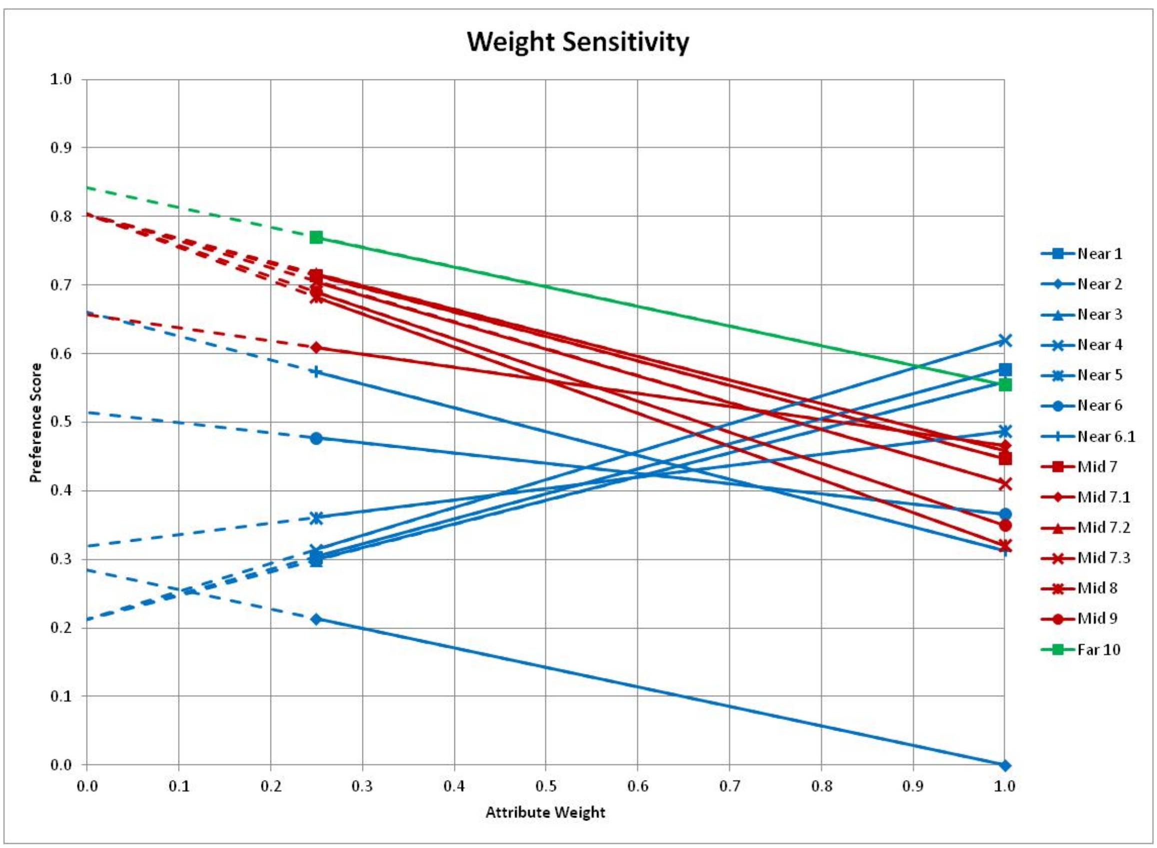

Figure 25. Weight Sensitivity

(ii) Day Recognition Range Factor. Day Recognition Range followed the same trend as Weight when the sensitivities were analyzed. As the weight of the factor was increased, the systems that utilized that factor also increased. Systems that had the maximum day recognition range received a score of one and systems that had the minimum day recognition range received a score of zero when the weight of day recognition was equal to one. If a system had a day recognition range somewhere between the minimum and maximum, the system would receive a score equal to the normalized value between the minimum and maximum ranges. This is due to the way that the model is setup. Day recognition range is normalized within the model and systems received scores based upon where they lied within the possible range of day recognition range. Also similar to the Weight factor analysis is that systems obtained scores based upon how much of the other factors they utilized when the Day Recognition Range factor had a weight of zero. This varied from system to system. See Figure 26 for the complete results of varying Day Recognition Range as a factor.

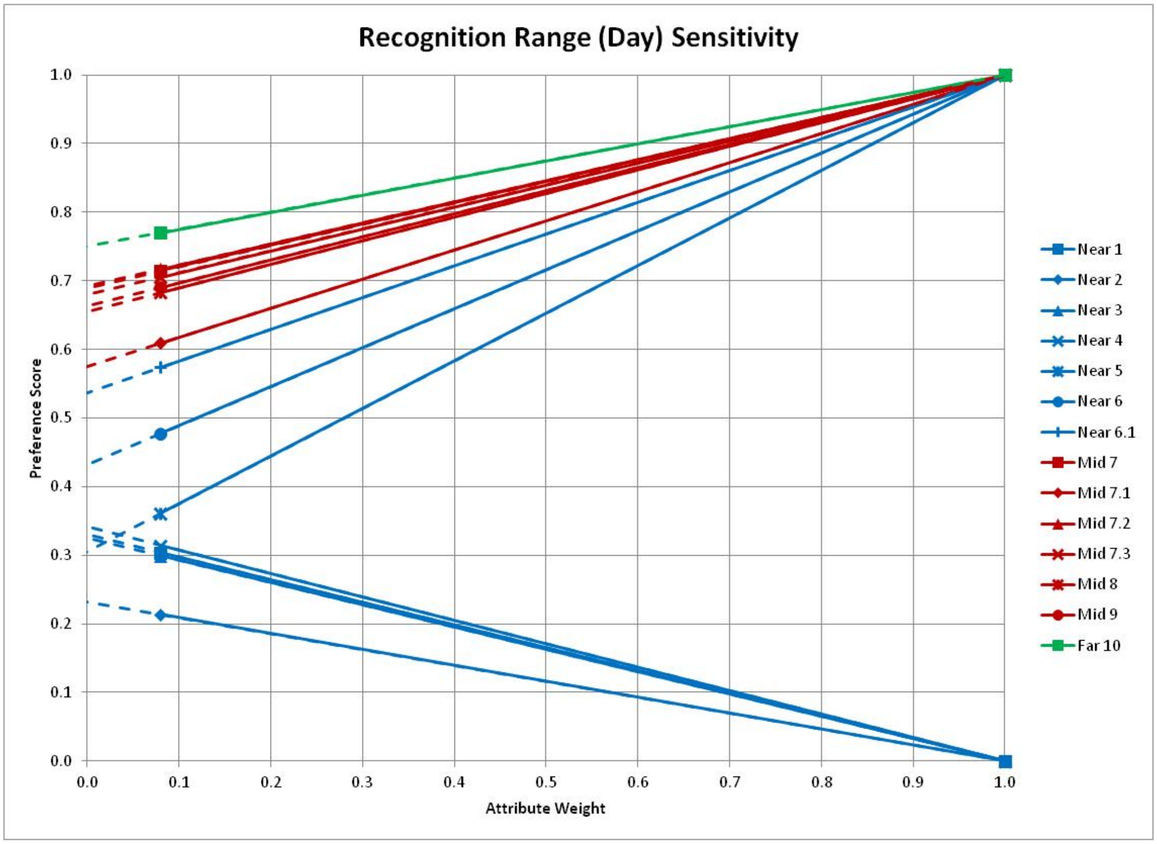

Figure 26. Recognition Range (Day) Sensitivity

(iii) Night Recognition Range Factor. The Night Recognition Range sensitivity follows the same trend as both of the previous two factors. No additional analysis was needed for this factor. See Figure 27 for the complete results of varying Night Recognition Range as a factor.

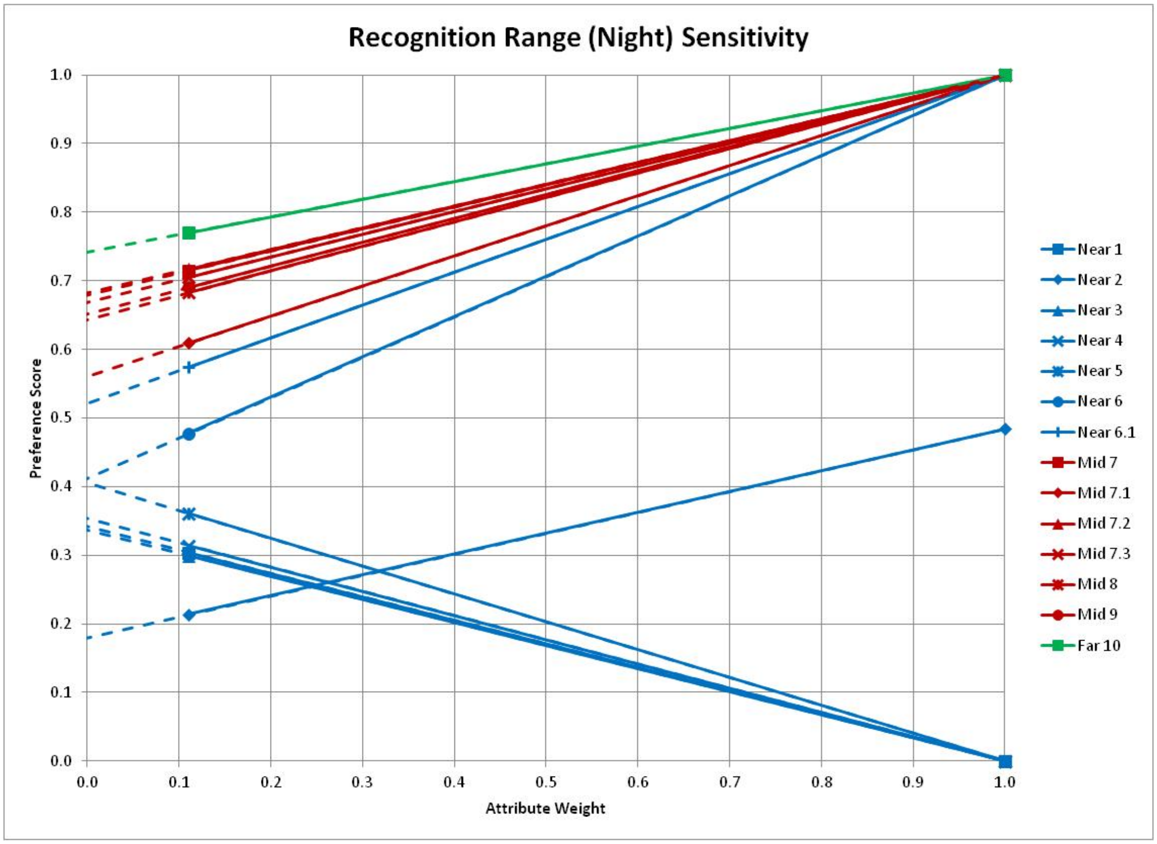

Figure 27. Recognition Range (Night) Sensitivity

(iv) Target Location Error Factor. As Target Location Error was varied from zero to a value of one, the resulting effect had the same impact on each of the systems in that they all tended to the same final value depending upon what type of system it was (i.e. near, mid, or far-term). This was due to the fact that all of the systems within the same near, mid, far time period had identical TLE performance because they all utilized the same equipment to reduce TLE. When the TLE weight was increased to one, there was nothing else to distinguish the different systems from each other. See Figure 28 for the complete results of varying TLE as a factor.

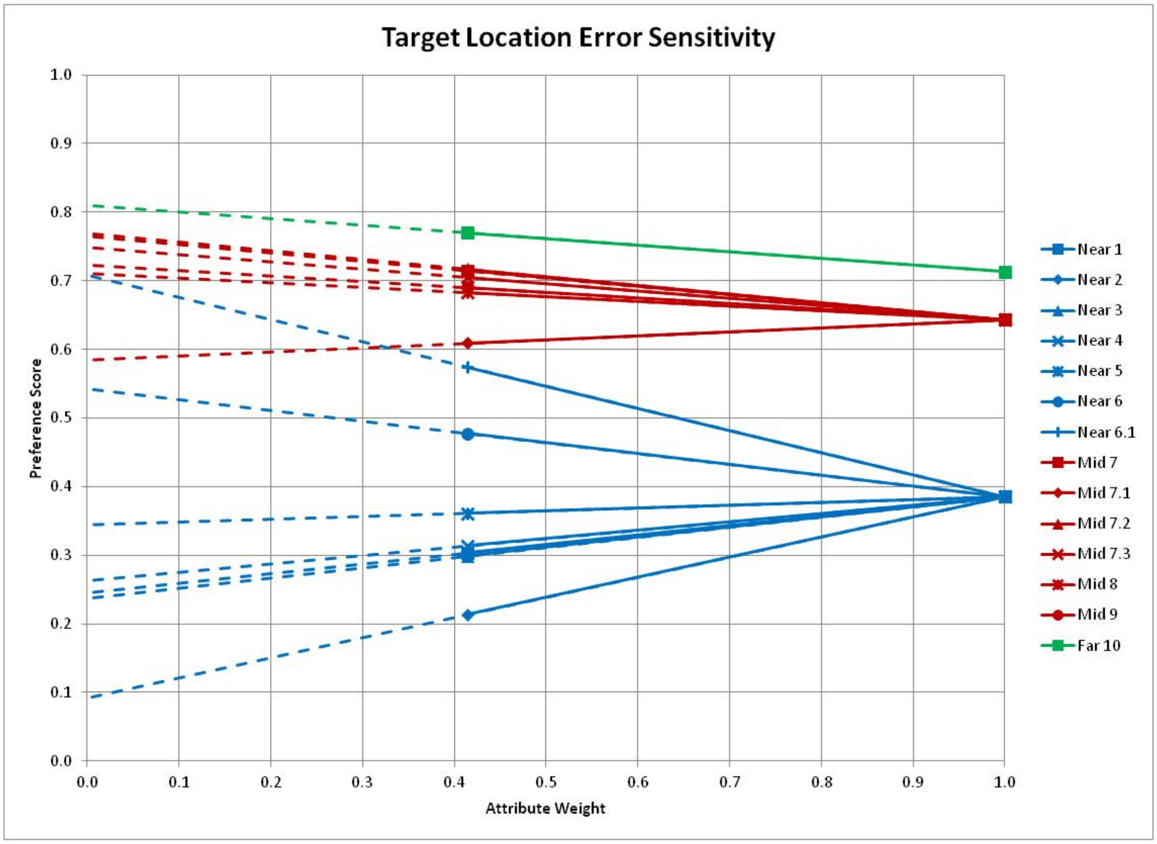

Figure 28. Target Location Error Sensitivity

(v) Designation Range Factor. The Designation Range sensitivity showed the same trends as the Weight and Recognition Ranges factors. No additional analysis was needed for this factor. See Figure 29 for the complete results of varying Designation Range as a factor.

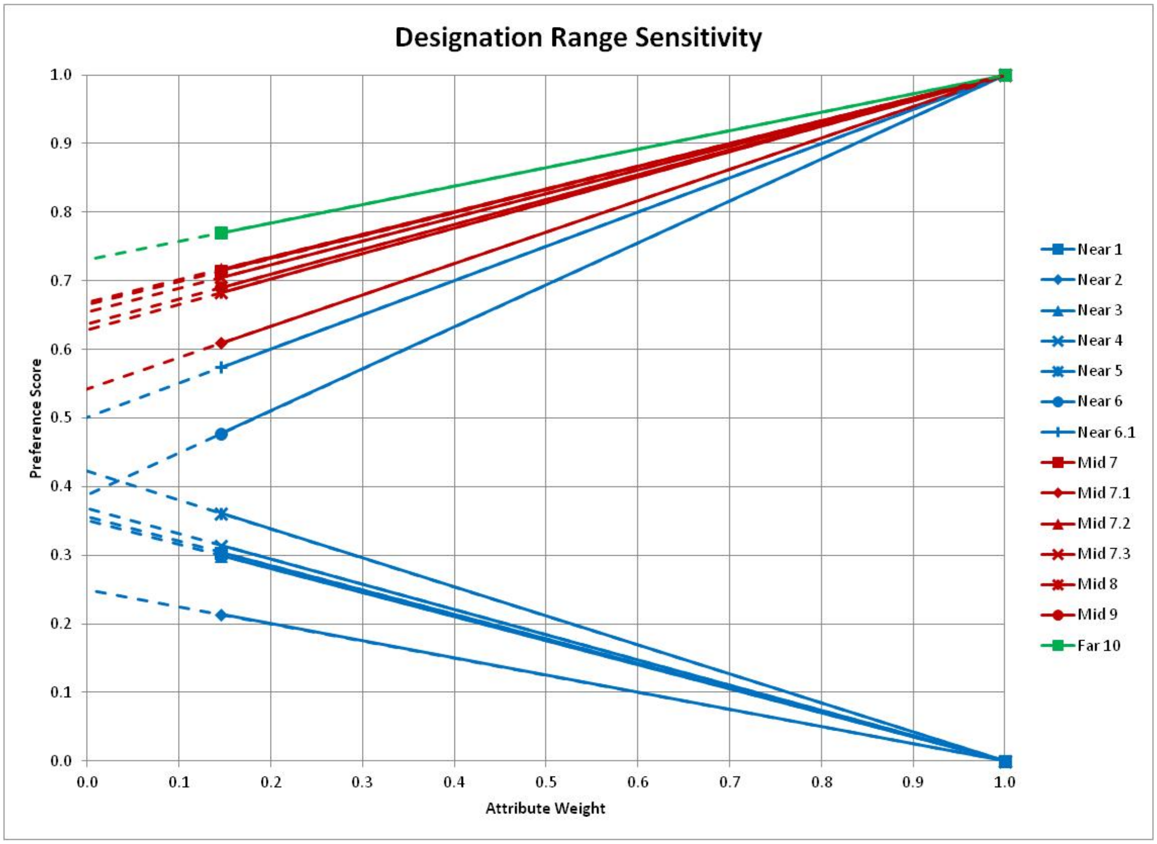

Figure 29. Designation Range Sensitivity

(b) Attribute Sensitivities. Sensitivity analysis was also conducted on the primary attributes; however, tornado diagrams were used because all factors collectively influence the final attribute.

(i) Attributes Affecting Preference. As a result of the sensitivity analysis, several attributes were found to have influence on the overall preference score of the system. The most influential attribute from the analysis was Theta, which was a factor that was used within the calculation of TLE. This was not a surprise given that TLE was the most highly weighted factor that determines the preference score of a system. This attribute appears to affect the preference of a system almost twice as much as any other attribute. The rest of the eight other attributes that affected overall preference still appeared to have a significant influence over the overall preference score, but none of them were as significant as Theta. A full list of attributes that affected the preference score of a system as well as the relative magnitudes of this effect can be found in Figure 30.

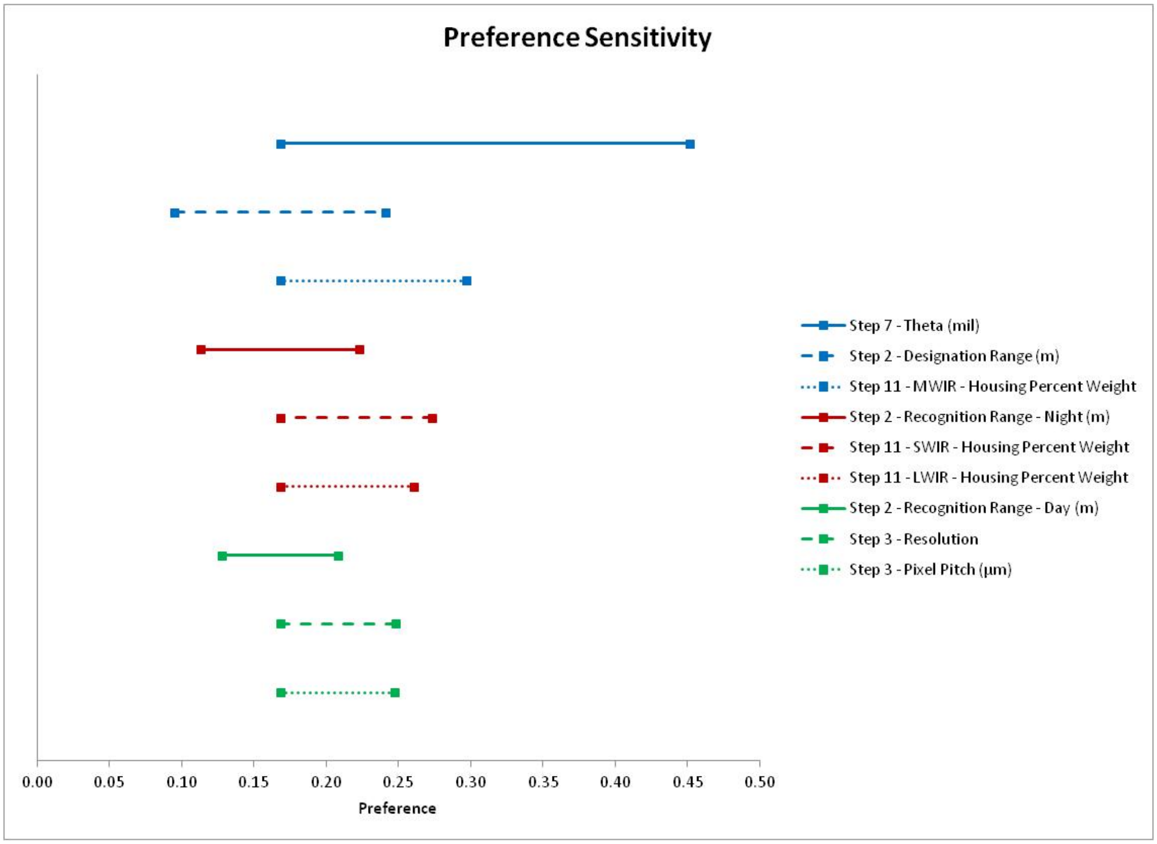

Figure 30. Preference Sensitivity Tornado Diagram

(ii) Attributes Affecting Weight. As the system is constructed by several smaller subsystems, there are many factors that individually contribute to the overall system weight. The most influential attributes from the analysis were the three different housing weight percentages. These three factors dominate the effects on weight far more than any other attribute and therefore are important in being as accurate as possible within the model. These attributes are used to determine the housing weight, or outer casing, of the simulated system after all other weights have been calculated. This at first did not appear as obvious, but upon thinking about how tornado diagrams are constructed, it make sense after some thought was put into it.

It should be noted that the results from the tornado diagram are slightly skewed even though the appropriate method was followed when it comes to the housing weight percentages. In calculating the effects of any attribute on the weight of the system, one variable was varied at a time from the minimum value to the maximum value. The difference in system weight was recorded during the variation and the same process was repeated for all attributes. Then all differences in weight were plotted on a chart. This caused a slight problem when calculating the differences in weight for the housing weight percentages. Since the percentages can be taken up to a maximum of 99.99%, this significantly inflates the weight of the housing. This means that whatever the total weight of all of the subsystems within the system totaled to, the housing weight was calculated as being 9,999 times that value (for purposes of the tornado diagram). This is not very realistic, but it was not corrected given the procedure for creating a tornado diagram.

There were several other attributes that appeared to affect the system weight besides the housing weight percentages. Resolution and pixel pitch were the next four most influential attributes when considered as separate attributes for both the day and night recognition systems. A full list of attributes that affected the weight of a system as well as the relative magnitudes of this effect can be found in Figure 31.

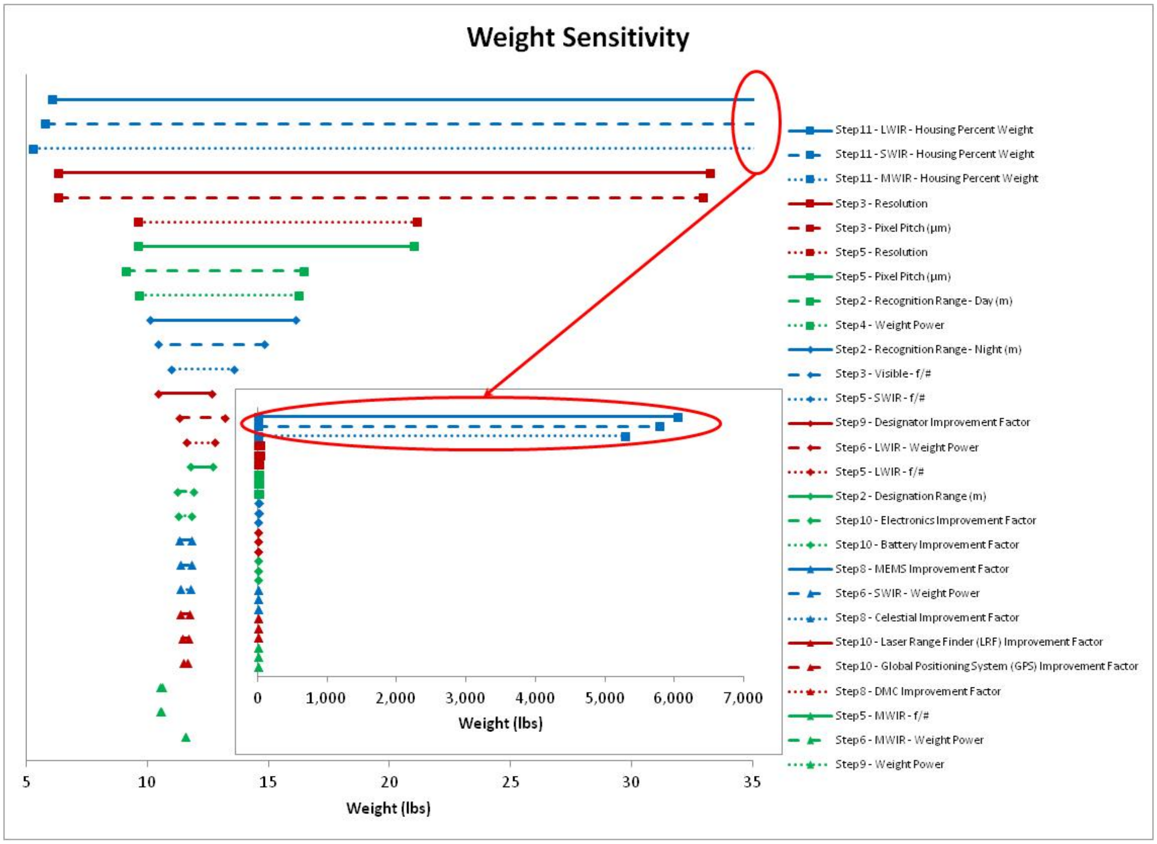

Figure 31. Weight Sensitivity Tornado Diagram

(iii) Attributes Affecting Target Location Error. As seen in the Preference tornado diagram, Theta was the factor that affected the system most and it did it through influencing TLE. Therefore, it was not a surprise to see that Theta was the only real attribute that had any significant impact on TLE within this tornado diagram. A full list of attributes that affected the TLE of a system as well as the relative magnitudes of this effect can be found in Figure 32.

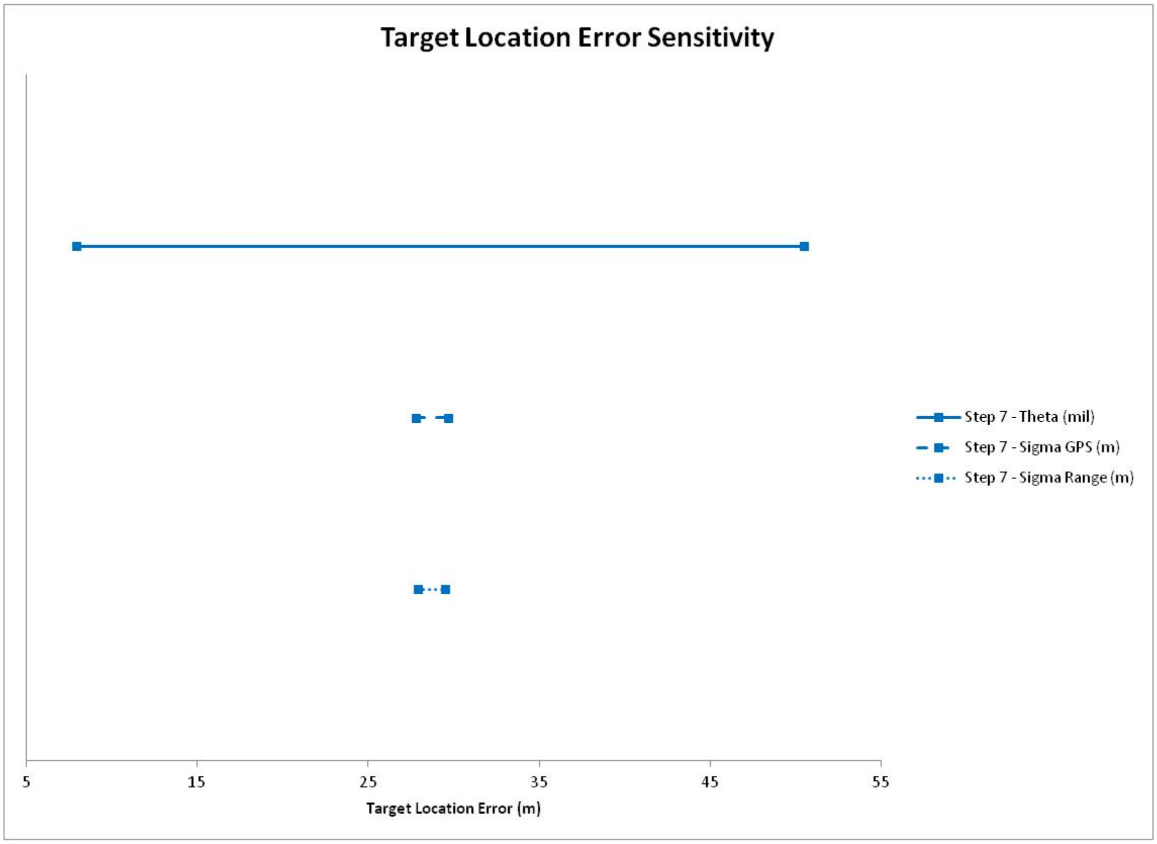

Figure 32. Target Location Error Sensitivity Tornado Diagram

e. Complete AoA Products

All of the documents developed during the AoA were compiled and presented at an IPR. This included all the products of the AoA tasks, including the solution space, simulation products, and potential solutions.

The sequence of events for completing the final research documents was as follows:

- Collect and finalize the solution space, simulation products, potential solutions, and any other products developed during this phase

- Present the products for a final review to CD&I/MCCDC for approval and selection of potential solutions that will be considered during the Technology Roadmap Phase

3. Technology Roadmap and Modernization Plan Phase

This phase developed technology roadmaps to show the insertion points of technology into the potential solutions based on the technology development at ONR and the state of the technology at program initiation. In some cases, the material solution is planned to be developed and fielded with pre-planned technology insertions as technology becomes available. In other cases, the current equipment will be phased out and replaced when new technology is available sometime in the future. Neither strategy is without risk, as technology development is notoriously difficult to predict and future S&T investment dollars are anything but certain.

To facilitate the development of the JTAC-SLM as well as influence the design of the ongoing CLRF-IC program, a TRMP was developed. This plan was completed in several recursive steps. First, the ongoing developments by ONR and Army NVESD were investigated. Second, these development timelines were aligned with the near, mid, and far-term developments of the CLRF-IC and JTAC-SLM programs and were included in the system performance model. The impacts of the technologies shown in overall system preference score in the model were used to develop the final TRMP. Finally, the risks associated with each technology were analyzed.

The results of the system performance model and sensitivity analysis were combined with technology development plans and physical models to determine the candidates for technology development. These represent the best balance of technical feasibility, technical risk, cost, and increase to system performance. In short, these represent the best “bang for the buck” to the JTAC-SLM system.

It is important to note that the TRMP presented in this paper represents the expected actual plan of MCSC, CD&I/MCCDC, and ONR for the modernization of handheld targeting equipment. The plan presented here is up to date as of the publishing of this paper but as a living document; the TRMP will be adjusted to reflect technology maturity, program development, and fiscal realities.

a. Align Technology Development and Potential Solutions

The TRMP summary is shown in Figure 33. It is labeled "DRAFT" because it has not yet been approved by MCSC but it has been released to ONR in its current form. The technology improvements are heavily concentrated on improving the azimuth sensor, which is the key technology required to reduce TLE. This will be explained in further detail in the subsequent sections. The other technology improvement effort is for an integrated day/night imager, which has the potential to reduce system weight and thus improve overall system score.

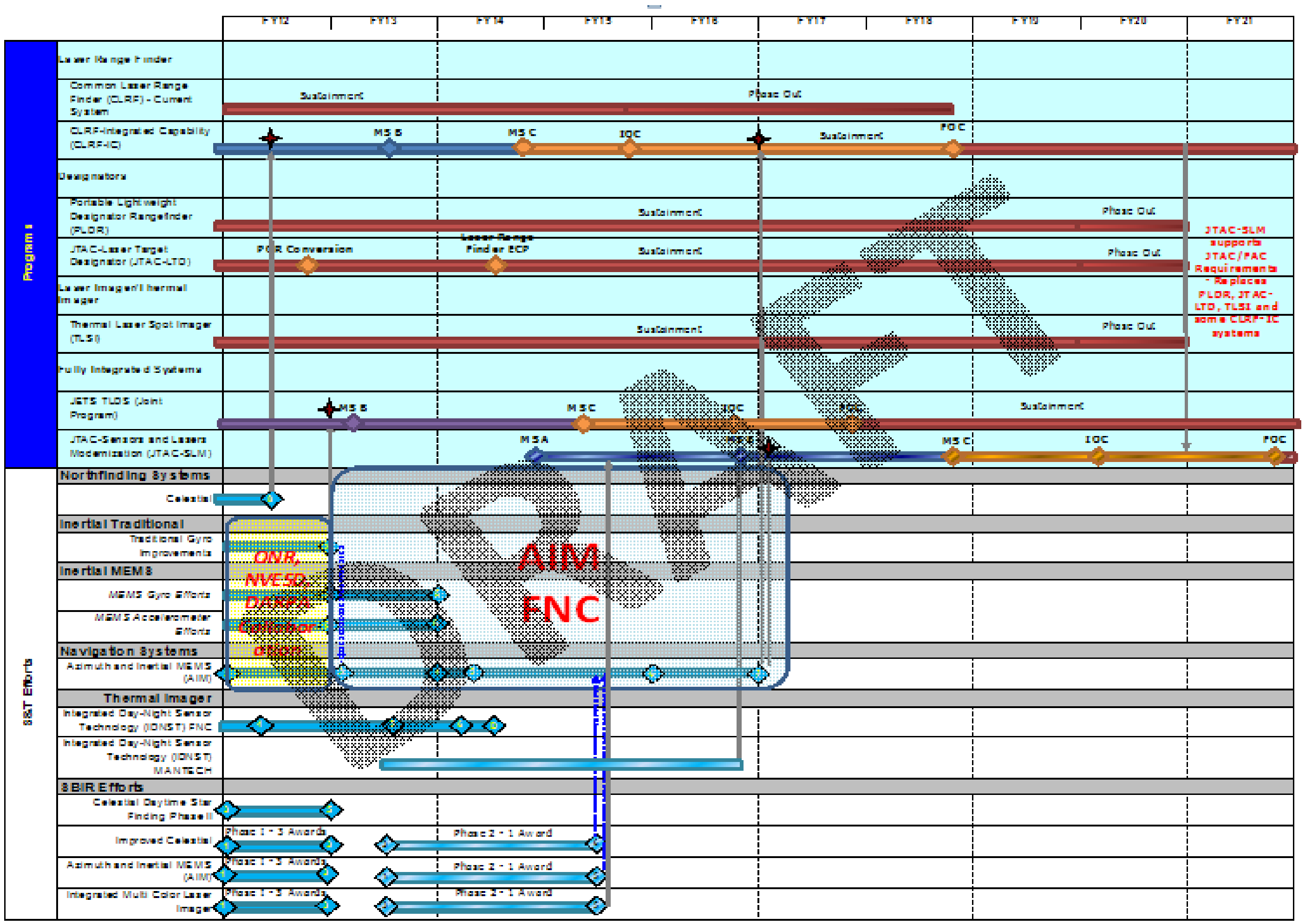

Figure 33. JTAC-SLM Technology Roadmap and Modernization Plan

The sequence of events for completing the Align Technology Development and Potential Solutions task was as follows:

- Collect latest ONR and other partners S&T plans
- Develop Technology Roadmap based on planned S&T development and maturity
- Develop S&T development suggestions for consideration by ONR

(1) Azimuth Technology Improvements. According to the results of the user surveys, TLE is the most important user preference. The results of the system performance models and sensitivity analysis confirm that this has the largest impact on overall system score.

The TLE generated by the system is actually a combination of self-location error (GPS), range error (LRF), and cross-range error, as shown in Figure 34.

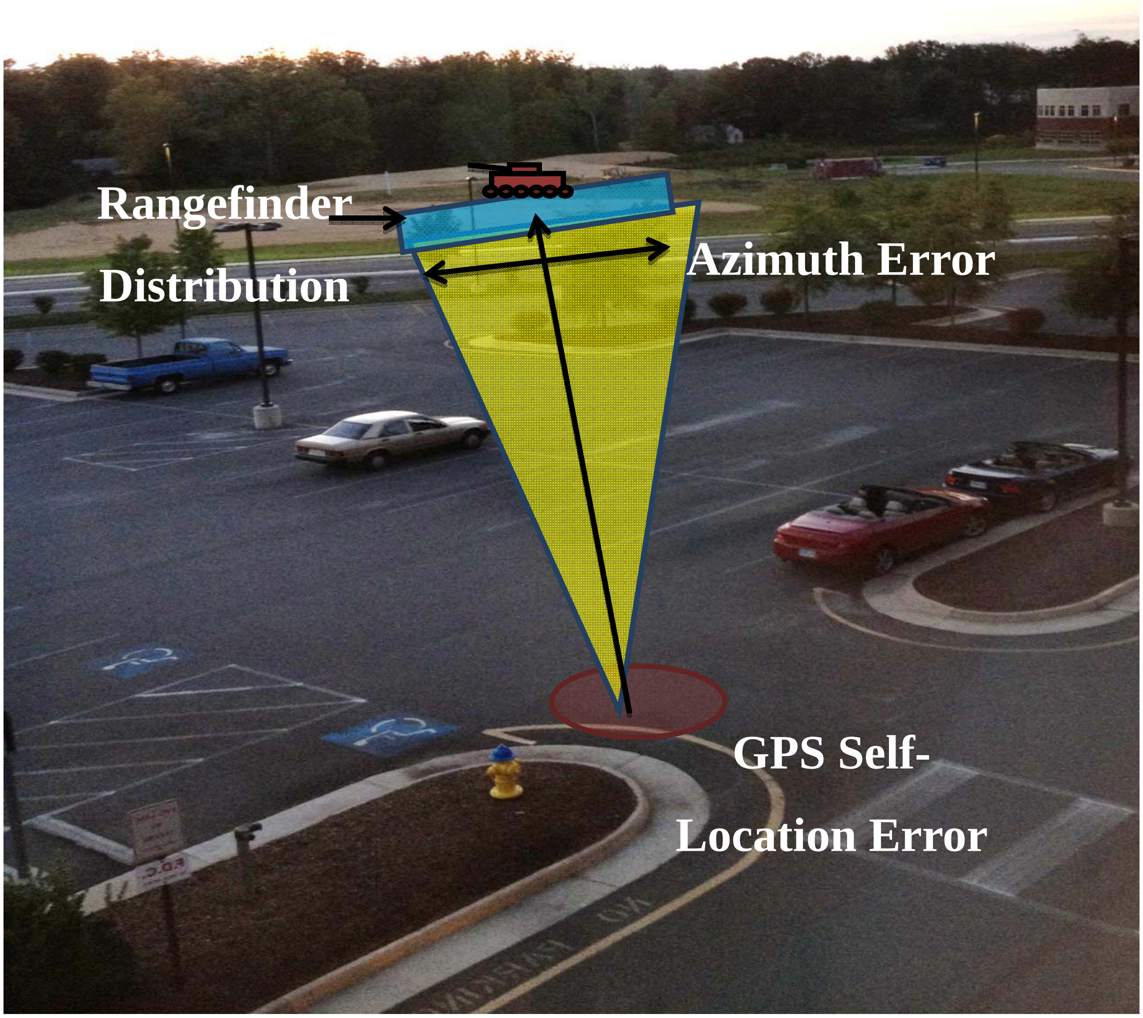

Figure 34. Target Location Error Components

The azimuth sensor is by far the largest contributor to TLE using today's components. The major reason for this is that the cross-range component of TLE is the Root Sum Square combination of GPS (which is a small but not insignificant part of TLE) and the azimuth error times range, as is seen in **Equation 13**. The downrange component isn't as significant, and is shown in **Equation 14**. The derivation of TLE from these components is beyond the scope of this paper, but can be found in a separate report [18].

$$\sigma_{Crossrange} = \sqrt{\sigma_{GPS}^2 + Range_{km}(\sigma_{Azimuth\ Sensor}^2)}$$

Equation 13: Cross-range Component of TLE

$$\sigma_{Downrange} = \sqrt{\sigma_{GPS}^2 + \sigma_{Rangefinder}^2}$$

Equation 14: Downrange Component of TLE

Unfortunately, the current azimuth sensor in the CLRF (and every other handheld targeting device) is a DMC. This sensor has the advantage of determining azimuth very quickly but is affected by nearby magnetic fields, such as vehicles, pipes, buildings, and even items being worn by the user. Furthermore, DMCs measure the Earth's magnetic field, which must be converted to true north by adding/subtracting magnetic declination. Magnetic declination changes over time and the best models are only good to 18 mils [19]. Furthermore, the DMC cannot determine the azimuth measurement's accuracy. This can lead to gross errors which lead to large TLE's – a potentially dangerous situation. By doctrine, the USMC cannot call for precision guided weapons such as the Excalibur GPS guided 155mm artillery round if the targeting solution was determined using a DMC.

(a) Celestial Compass Azimuth Sensors. The next best technology currently available is a celestial compass. These sensors determine direction by the positions of the sun, moon, and/or stars. Although celestial azimuth determination has been in use for thousands of years, a sensor suitable for hand-held targeting has only recently been developed. ONR invested in celestial azimuth sensors earlier this decade on behalf of the USMC, and the Army was the first to benefit from this investment and subsequently installed the first sensors on their Lightweight Laser Designator Rangefinder (LLDR) targeting system in 2011. The USMC CLRF-IC will include a celestial azimuth sensor.

Celestial compasses are not without their shortcomings. The LLDR version has three cameras – one for day and two for night. At the time of the installation, there wasn't a single camera system capable of working both day and night. But with further investment by industry, the CLRF-IC will include a one-camera system – saving on weight and lowering logistical burdens. This is shown in the Technology Roadmap.

Celestial compasses also cannot see through clouds. This means that they only will function about 50% worldwide, according to Naval Surface Warfare Center Dahlgren Division (NSWCDD). MCSC is investing in two Small Business Innovation Research (SBIR) efforts to attempt to see through cloud cover. The Phase II effort has not yielded the desired improvement which is why it is not showing a transition line in the Technology Roadmap, but is included because the technology is still under development. The Phase I effort had three performers, with at least one showing enough promise to consider for a Phase II award.

Celestial compasses cannot reasonably be expected to achieve perfect availability. Even with these improvements, they will still have difficulty in urban canyons, and will never work in jungle canopy or indoors.

(b) Inertial Azimuth Sensors. Inertial Azimuth Sensors, like the celestial systems, have been around for many years. Existing systems that perform this function are called gyrocompasses. Gyrocompasses measure the Earth's rotation to determine true north. Fielded gyrocompasses rely on large, highly accurate gyroscopes and accelerometers for their measurements and are not suitable for hand held targeting. The only fielded system was developed for Special Operations Command (SOCOM) – the azimuth component weighs over two pounds and the systems cost over $250K per copy [20].

The challenges with inertial azimuth sensors lie in their size and azimuth determination time. Unlike DMC's and celestial azimuth sensors which provide a solution in under two seconds, inertial azimuth sensors can take minutes or hours to provide the needed accuracy. This is clearly a shortcoming of the technology.

Also, inertial azimuth sensors limit the rate at which the operator can move the system after it finds north, and if the user exceeds this rate the system must be restarted.

The DoD investment in inertial azimuth sensors has been and continues to be significant. The first attempts concentrated on improving traditional gyroscopes and techniques to utilize these technologies. Unfortunately, these technologies have hit their physical limits. The lessons learned from these investments, including modeling and software, is transitioning to the Azimuth and Inertial MEMS (AIM) effort as seen in the Technology Roadmap.

ONR is investing in MEMS based gyroscopes which will be much smaller than traditional gyroscopes. These gyroscopes are key components in the inertial azimuth sensor. Joining ONR is Aviation and Missile Research Development and Engineering Center (AMRDEC), Army PMO Soldier Sensors, and Defense Advanced Research Projects Agency (DARPA). The most promising technologies are disc resonating gyroscopes, which are manufactured via traditional silicon wafer etching methods. If this technology works out, these gyros will be very inexpensive, since they can be manufactured with traditional silicon wafer etching. The fallback position is the same design but etched in quartz. This will be more expensive to manufacture but quartz gyros have the potential to have lower noise than silicon gyros. There is another technology being worked, but since it is proprietary it is not included in this report. All of these are candidates for the Azimuth and Inertial MEMS program.

(2) Imager Technology Improvements. The sensitivity analysis showed that pixel size doesn't have much impact on overall score, and the best overall score is achieved for MWIR based night vision. However, SWIR technologies perform almost as well and have some desirable features that are lacking in MWIR. ONR is working on an improved un-cooled SWIR sensor called Integrated Day Night Sensor Technology (IDNST), but won't be ready in time for CLRF-IC. It is scheduled to achieve Technology Readiness Level (TRL) 6 and Manufacturing Readiness Level (MRL) 6 in time to be inserted into the JTAC-SLM as shown in the TRMP [21].

The IDNST program had the goal to combine a SWIR and day imager in one sensor, and provide laser spot imaging as well. Unfortunately, the goal of merging the day and SWIR sensors has been too challenging and won't be available in time for even the far-term system. While the program is still under development, one of the competing designs is a Cassegrain reflective optic. Reflective optics have the advantage that they are wavelength independent, while refractive (lens) systems bend light differently depending on their wavelength. This gives the design the flexibility to change wavebands (SWIR/MWIR/LWIR) without having to redesign the whole system. Another very valuable aspect of IDNST is the elimination of the SWIR cooler. This will not only reduce system weight due to elimination of parts, but also lowers the power consumption which reduces battery weight. There are other advantages of SWIR technology over MWIR and LWIR that make IDNST a program worthy of inclusion in the Modernization Plan.

Another technology being watched is black silicon. Traditional silicon is sensitive in the visible light band and slightly into the Near Infrared (NIR) band. One reason for this is that silicon is transparent to IR light, and if it can't absorb the photons it can't provide a signal. Black silicon, like its name suggests, is "dark" to IR light. The current technology has extended further into the NIR band and is approaching the SWIR band. Black silicon has many advantages over other sensor technologies – it is sensitive to visible light, it won't require cooling, and it will be far less expensive to manufacture than Indium Gallium Arsenide (InGaAs) or Mercury Cadmium Telluride (HgCdTe) sensors. This sensor is being considered for IDNST.

b. Risk Analysis

Development of these new technologies is not without risk. The method used to identify and categorize risks was found in the DoD Risk Management Guide [22]. The method was tailored to align with the S&T nature of the technology development, and some liberty was taken on the schedule risk since the midterm and long-term programs haven't been fully developed.

The sequence of events for completing the Risk Analysis task was as follows:

- Analyze ONR and other partners S&T plans for technology readiness and risks
- Develop risk matrix for each Technology Roadmaps technologies

(1) Methodology. Each technology was assessed for technical, schedule, and cost risks to the near-term (CLRF-IC), mid-term (CLRF-IC ECP's and JTAC-SLM), and far-term (JTAC-SLM ECP's) according to the program targeted. The targeted programs can be seen in the TRMP.

The likelihood rating was completed using the criteria outlined in the DoD Risk Management Guide [22] shown in Table 22.

Table 22. Levels of Likelihood Criteria

Level	Likelihood	Probability of Occurrence
1	Not Likely	~10%
2	Low Likelihood	~30%
3	Likely	~50%
4	Highly Likely	~70%
5	Near Certainty	~90%

Similarly, the consequence criteria were tailored from the DoD Risk Management Guide [22]. The tailoring was the elimination of hard stops for schedule slip and budget impacts. This was done according to the professional opinion of the MCSC S&T SME and ONR and is shown in Table 23.

Table 23. Levels and Types of Consequence Criteria

Level	Technical Performance	Schedule	Cost
1	Minimal or no consequence to technical performance	Minimal or no impact	Minimal or no impact
2	Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program	Able to meet key dates	Budget increase or unit production cost increase
3	Moderate reduction in technical performance or supportability with limited impact on program objectives	Minor schedule slip. Able to meet key milestones with no schedule float	Budget increase or unit production cost increase
4	Significant degradation in technical performance, or major shortfall in supportability, may jeopardize program success	Program critical path affected	Budget increase or unit production cost increase
5	Severe degradation in technical performance. Cannot meet KPP or key technical/supportability threshold; will jeopardize program success	Cannot meet key program milestones	Exceeds APB threshold

(2) Celestial Azimuth Sensor Risk Assessment. The CLRF-IC is being designed with a celestial compass that is technically mature and proven by Army fielding and usage. The existing compass does not function under cloud cover and can only perform 50% of the time worldwide when weather alone is considered. The general

rule of thumb is that if the user can see his shadow, the celestial compass will find a solution. The backup to the celestial compass is the DMC, which is well known to have serious performance issues.

MCSC has two ongoing SBIR's attempting to increase the sensor's ability during times of cloud cover. These are shown in the TRMP. It is important to note that the existing celestial compass is acceptable because it meets the CLRF-IC's threshold requirement, but higher availability is strongly desired. If the improvements to the celestial azimuth sensor fail, the current sensor will continue to be used. Therefore, none of the consequences rate higher than Level 2. The celestial azimuth sensor risk assessment is shown in Table 24 and the summary is shown in Figure 35.

Table 24. Celestial Azimuth Sensor Risk Assessment

Azimuth Sensor: Celestial Compass						
Num.	**Type**	**Description**	**Likelihood**	**Consequence**	**Strategy**	**Rationale**
1	Performance	Inability to see through clouds	4	2	Retain	This effort is a performance enhancement on an existing system. If this improvement fails, system will continue to use existing compass which meets threshold but not objective CLRF performance requirement.
2	Performance	Usability	3	2	Retain	Some performance improvement can be realized by limiting field of view and requiring user to point at a clear area of sky. Early feedback on prototype systems will enable early abandonment should this not be acceptable.
3	Schedule	Failure to achieve TRL 6 on schedule	3	1	Retain	Currently scheduled as a CLRF-IC ECP. Move to JTAC-SLM if schedule slips or abandon entirely.
4	Cost	Unaffordable in budget climate	2	1	Retain	This technology, if it works, will be very affordable. If it fails to meet anticipated cost, continue to use existing celestial compass.

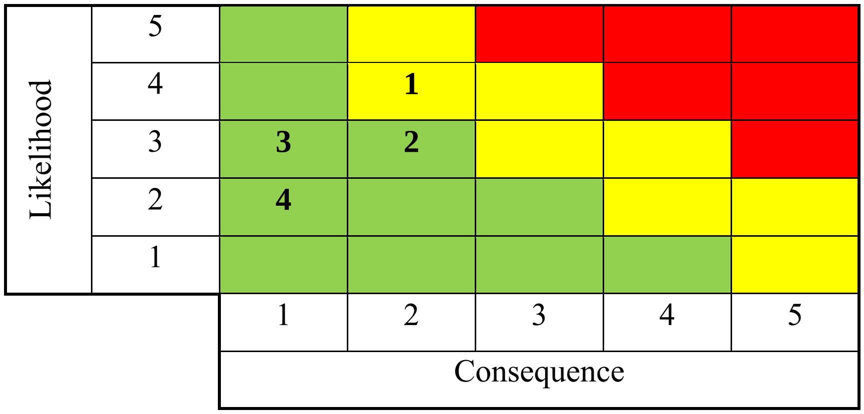

Figure 35. Celestial Azimuth Sensor Risk Summary

(3) Inertial Azimuth Sensor Risk Assessment. As mentioned earlier, inertial azimuth sensors function everywhere because they sense the rotation of the earth, therefore they are highly desirable as an augmentation to celestial azimuth sensors and DMC's. This technology will not completely replace the other two azimuth sensors even in the far-term, because inertial sensors have usability limitations including requiring the user to keep the sensors still while they measure the rotation of the earth and they require a significant amount of time to converge to a solution. Even under ideal circumstances, the inertial azimuth sensor won't achieve the accuracy that celestial compasses provide.

ONR has invested substantial resources developing an inertial azimuth sensor. Joining ONR is the Army NVESD, Army PMO Soldier Sensors and Lasers, SOCOM, Johns Hopkins University APL, and DARPA. The reason for this large coalition is because the problem is very difficult and requires cooperation to ensure that efforts aren't duplicated nor wasted. Industry is part of this coalition, with annual briefings given at the National Defense Industrial Association (NDIA) Joint Precision Azimuth Sensing Symposium (JPASS).

The most promising technology is MEMS based gyroscopes, the critical component to celestial azimuth sensors. There has been good progress made in recent years, and if this technology pans out it has broad application within and beyond DoD, as it will be very inexpensive.

Because of the large investment given by ONR, there is a three party agreement between ONR, MCSC, and CD&I/MCCDC called a Technology Transition Agreement (TTA). This agreement lays out the program technical plan, the performance/schedule/cost requirements, and the transition plan. TTAs are reviewed and edited every year by the three parties, and they become more detailed and require higher commitment as the program progresses. The TTA effectively transfers the majority of the risk to ONR, provided that MCCDC agrees to support a Program Objective Memorandum (POM) initiative for the program and MCSC agrees to integrate it into a new or existing program.

The current TTA dictates that the AIM program achieve five mil accuracy in 120 seconds, mature in TRL according to the TRMP, and cost less than $5k per unit. If the technology achieves these difficult goals the program is almost certain to transition. If these goals are not met, the Army is likely to be the first adopter because they have larger coffers, and the Marine Corps will have to wait until the Army production drives the cost down.

The development schedule of CLRF-IC will not support waiting for the AIM sensor. To ease integration, the TTA dictates that ONR develop an Initial Capabilities Document (ICD) for the AIM inertial azimuth sensor in FY12. This will enable the CLRF-IC program to include an interface that will accept the AIM sensor once it becomes available. The current plan is to incorporate the AIM sensor via an ECP. The low unit cost makes this very attractive and may be possible without requiring a new POM issue, which lowers the impacts of a schedule slip.

The risks for this program must be managed well to enable the procurement and integration of the AIM inertial azimuth sensor into CLRF-IC. If the schedule slips so much that CLRF-IC cannot accept the technology due to end of service life issues, the sensor will instead be integrated into the JTAC-SLM program. The inertial azimuth sensor risk assessment is shown in Table 25 and the summary is shown in Figure 36.

Table 25. Inertial Azimuth Sensor Risk Assessment

Azimuth Sensor: Inertial MEMS						
Num.	**Type**	**Description**	**Likelihood**	**Consequence**	**Strategy**	**Rationale**
1	Performance	Inability to meet accuracy requirement	3	3	Reduce	Continue to work with DoD partners. Perform early tests on MEMS component to identify shortfalls early in the development effort. Switch from Silicon to Quartz if required.
2	Performance	Inability to meet measurement time requirement	3	2	Retain	The need for high accuracy is only needed at long ranges. At short ranges even a poor sensor will be adequate. Long ranges also imply that the user has more time before a measurement is required.
3	Performance	Failure to meet CLRF-IC ICD	2	4	Reduce / Transfer	MCSC is requiring an ICD from ONR very early in the program (FY12) to ensure that the CLRF-IC will be designed to accept the sensor.
4	Performance	Usability	2	2	Reduce	TRL 5, 6, and 7 prototypes will be assessed by users while the program is still in the S&T Phase (FY14-17).
5	Schedule	Failure to achieve TRL 7 on schedule	3	2	Retain	If the system doesn't meet schedule for CLRF-IC, the introduction of the technology will occur with the JTAC-SLM.

Azimuth Sensor: Inertial MEMS						
Num.	**Type**	**Description**	**Likelihood**	**Consequence**	**Strategy**	**Rationale**
6	Cost	Failure to meet cost goal	3	2	Transfer	Utilize Technology Transfer Agreement to transfer to ONR. If system is too expensive, the Army may become the first adopter - just like the first generation celestial compass.
7	Cost	High cost of Quartz Sensor (only if Quartz is required)	2	2	Transfer	Utilize Technology Transfer Agreement to transfer to ONR. If system is too expensive, the Army may become the first adopter - just like the first generation celestial compass.

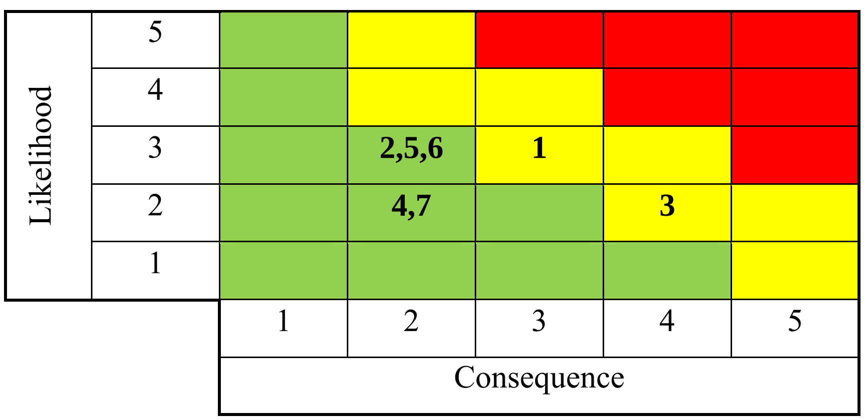

Figure 36. Inertial Azimuth Sensor Risk Summary

(4) Imager Technology Risk Assessment. The most promising imager technology improvement effort is the IDNST program mentioned earlier. The IDNST is being developed for medium and heavy machine gun sights, but the need spans far beyond this community, including the JTAC users. If day and night imagers were

combined, then those two modules would become a single module, with potential weight savings. However, the optics will be more complicated, limiting the potential weight savings.

Like the AIM program, IDNST program requires a TTA. Since IDNST is targeted at machine gun sights, the MCSC signatory is Infantry Weapons. PdM FSS plans to track the IDNST program and coordinate efforts with Infantry Weapons to track IDNST.

Unlike the celestial and inertial azimuth sensors, the imagers and optics are tightly integrated into the CLRF-IC and JTAC-SLM products. This means that if the IDNST technology isn't ready on time, it cannot be integrated into the programs later.

Fortunately, the IDNST technology isn't required to meet system requirements, therefore no risk consequence is higher than Level 1. The imager technology risk assessment is shown in Table 26 and the summary is shown in Figure 37.

Table 26. Integrated Day/Night Sight Risk Assessment

Imager: Integrated Day/Night Sensor						
Num.	**Type**	**Description**	**Likelihood**	**Consequence**	**Strategy**	**Rationale**
1	Performance	Failure to meet Day/Night Recognition Range	3	1	Retain	Current technology will meet requirement, IDNST technology will reduce weight if it works.
2	Performance	Overweight	3	1	Retain	Current technology will meet requirement. IDNST won't be adopted if it doesn't reduce overall system weight.
3	Schedule	Failure to meet JTAC-SLM Timeframe	3	1	Retain	Current technology will meet requirement. If IDNST doesn't meet JTAC-SLM timeframe the technology won't be utilized until JTAC-SLM is replaced.
4	Cost	Failure to meet JTAC-SLM Cost Goals	4	1	Retain	Current technology will meet cost goals.

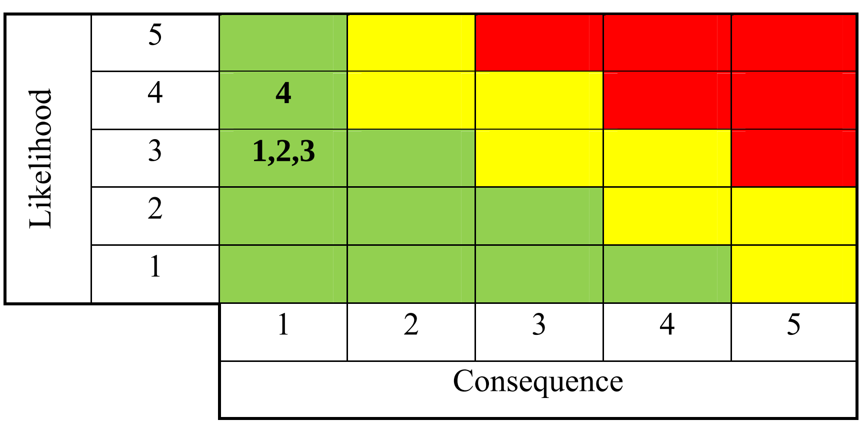

Figure 37. Integrated Day/Night Sensor Risk Summary

c. Complete Technology Roadmap and Modernization Products

All of the documents developed during the TRMP were compiled and presented for a final review. This includes the Technology Roadmaps and Risk Analysis for each potential solution.

The sequence of events for completing the final research documents was as follows:

- Collect and finalize the Technology Roadmaps, Risk Analysis, and any other products developed during this phase
- Present the products for a final review to all project specific stakeholders

4. Final Report

This Final Report is a collection of all the products developed during this capstone project, as well as the summaries of the reviews, and the recommendations for further work. This was documented in accordance with Naval Postgraduate School (NPS) Capstone Project Thesis guidelines.

C. TECHNOLOGY AND MODEL LIMITATIONS

Since the JTAC-SLM capstone project was considering the tradable functions for the candidate systems, some of the technologies which provide those functions have additional limitations that weren't analyzed in the model. For example, some of the technologies require a start-up time before they can provide the required function at full performance level, but start-up time wasn't part of the analysis. This was done to limit the scope of the capstone project and allow trades of the "heavy hitters". The intent of this capstone project isn't to discover the "best" solutions, but instead to provide quantitative information to inform a decision.

1. Night Vision Technologies

Night Vision is a key function for the JTAC-SLM, and it is also one of the most difficult to properly evaluate. Each technology looks in a different waveband of the electromagnetic spectrum [23], as is shown in Figure 38.

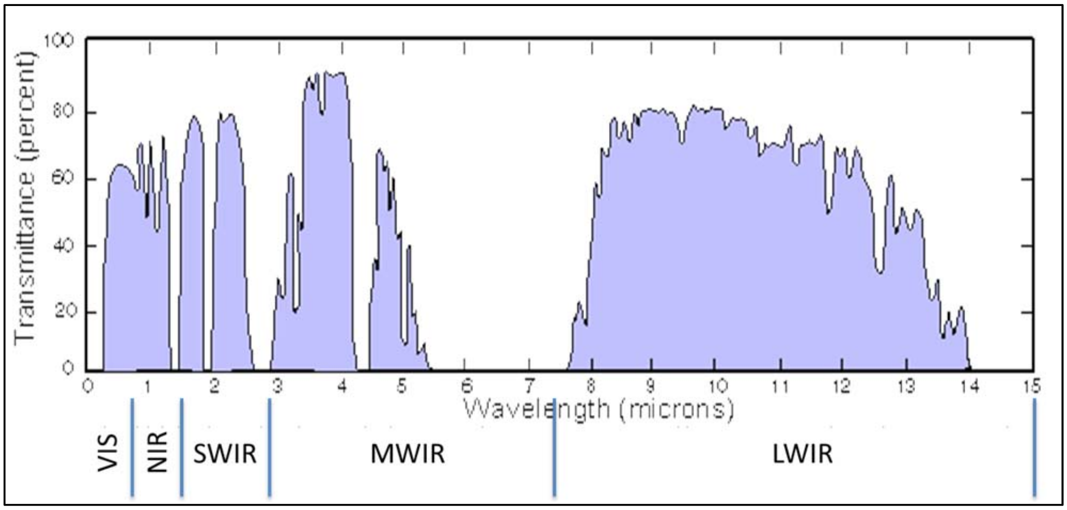

Figure 38. Atmospheric Absorbsion and Wavebands, After [23]

Visible light, NIR, and SWIR require a light source (such as the sun, starlight, and urban lighting), to function [21]. They do not work in complete darkness. MWIR and LWIR are known as “thermal imagers” and utilize light irradiated by warm sources, such as humans and vehicles, so they can function in complete darkness.

Twice a day there is a time of “thermal crossover”. This occurs near dusk and dawn, when the temperature difference between objects is very low and therefore an imager that relies on these wavebands does not function during these times. LWIR and MWIR wavebands suffer from this phenomenon.

SWIR imagers can see through glass and discern between natural foliage and camouflage netting. The other wavebands cannot. SWIR, MWIR, and LWIR can see through smoke, but in different ways. SWIR can image all objects through smoke, while LWIR and MWIR can see warm objects better.

Currently, SWIR and MWIR sensors require cooling before they can perform their function. This cooling can take several minutes and can impact mission success. Coolers also add weight and require power to run. LWIR sensors can use simpler Thermal Electric Coolers (TEC) and are ready to function in a shorter timeframe.

SWIR and MWIR sensors can see the 1064nm laser designator spot if the optics are designed with a window around 1064nm. This is possible because the base technologies have sensitivity beyond the targeted wavebands. LWIR imagers are not sensitive to 1064nm light and therefore cannot function as laser spot imagers.

A summary of the comparison between night vision technologies [19] is shown in Table 27.

Table 27. Night Vision Technology Comparison

	Total Darkness	**Through Windows**	**Thermal Crossover Sensitivity**	**Haze and Smoke**	**Designator Spot**	**Cooldown Time**	**Cost**
Image Intensifiers	No	No	None	Poor	No	None	Low
SWIR	No	Yes	Low	Good	Yes	Minutes (Near-Term) Seconds (Far-Term)	High (Near-Term) Low (Far-Term)
MWIR	Yes	No	Medium	Good	Yes	Minutes (Near-Term)	High (Near-Term)
LWIR	Yes	No	High	Good	No	About One Minute	Medium/ Low

The model does not capture the cooling time of the technologies as startup time was not one of the key system functions. Since laser spot imaging is one of the key functions, SWIR and MWIR imagers are the only technologies considered for the mid-term and far-term systems. LWIR and Image Intensifiers are the only technologies available for near-term, due to the high cost of the SWIR and MWIR systems.

2. Azimuth Sensor Technologies

Target location error has the highest user preference weight, and TLE is most affected by the choice of azimuth sensor. There is no perfect azimuth sensor, each technology has significant limitations.

Digital magnetic compasses are the oldest azimuth sensors. They function by detecting the earth's magnetic field and determining the pointing direction within that field. Unfortunately, the field is affected by nearby ferrous objects, such as vehicles, buildings, electrical currents, and even items worn by the user. A further complication is that the earth's magnetic field doesn't point to true north. This difference is computed using the World Magnetic Model. The difference between the earth's magnetic field and true north changes over time and is only known to one degree (on average) worldwide [24]. DMC's don't have a reliable method to determine if they are giving a good reading or if the measurement has error, causing an unsafe condition.

Determining direction by celestial measurements has been around for hundreds, if not thousands, of years. The celestial compass developed by ONR uses the same principle, but computes the direction automatically day or night. The limitation is that the sensor must have a clear view of the sky. Even in the open, celestial compasses function only about 50% of the time worldwide/year round due to cloud cover [25].

Inertial sensors have also been utilized to determine direction for many years. These devices are also called gyrocompasses, a system familiar to Navy sailors. They function by detecting the rotation of the earth and taking advantage of Newton's Second Law of Motion. Unfortunately, these devices take time to detect the earth's rotation, a limitation that is easy to deal with on ships but difficult in a ground battle. The sensors under development are MEMS based and will be made out of silicon. They will provide measurements under all conditions, but require some time to do so. While they hold the promise to provide sub-mil accuracy, they won't achieve this for many years.

A summary of the azimuth technologies is shown in Table 28.

Table 28. Azimuth Technology Comparison

	Stated Accuracy	**Fundamental Limitations**	**Time to Measure**	**Provide Reliable Estimate of Error**	**Cost**
Digital Magnetic Compass	10 mils	Electromagnetic interference World Magnetic Model inaccuracies	< 1 second	No	< $500
Celestial Compass	5 mils	Require clear view of sky (50% Worldwide)	1 second (Day) 2-10 seconds (Night)	Yes	< $3000
Inertial Azimuth Sensor	1-5 mils	Requires time to determine earth rotation Large motions require restart	120-240 seconds (first measurement) < 1 second (subsequent measurements)	Yes	< $5000 (est) Not yet available

The limitations of the different technologies, with the exception of the accuracy, are not accounted for in our model. Requiring multiple sensor types will increase system weight and could potentially show a lower overall score than a system without one of the sensors and also having a serious limitation. Fortunately, all these sensors are small and light. In the mid and far-term systems, it is reasonable to consider including as many technologies as is available.

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IV. RECOMMENDATIONS

The recommendations are presented in two major sections. First, a summary of the work done along with specific recommendations for decision makers to consider as part of the development of future equipment for the TACP suite will be presented. Secondly, the methodology used to develop those recommendations will be presented. It is the opinion of the capstone project team that the methodology is more important than the specific recommendations. The method used to develop the technical recommendations harmoniously blends all stakeholder interests, physical limitations, technology developments, and trade spaces – all while being heavily influenced by user input.

A. RECOMMENDATION METHODOLOGY

The specific methodology to develop the technical recommendations is described in Section 3 and is summarized in flowchart form in Figure 39.

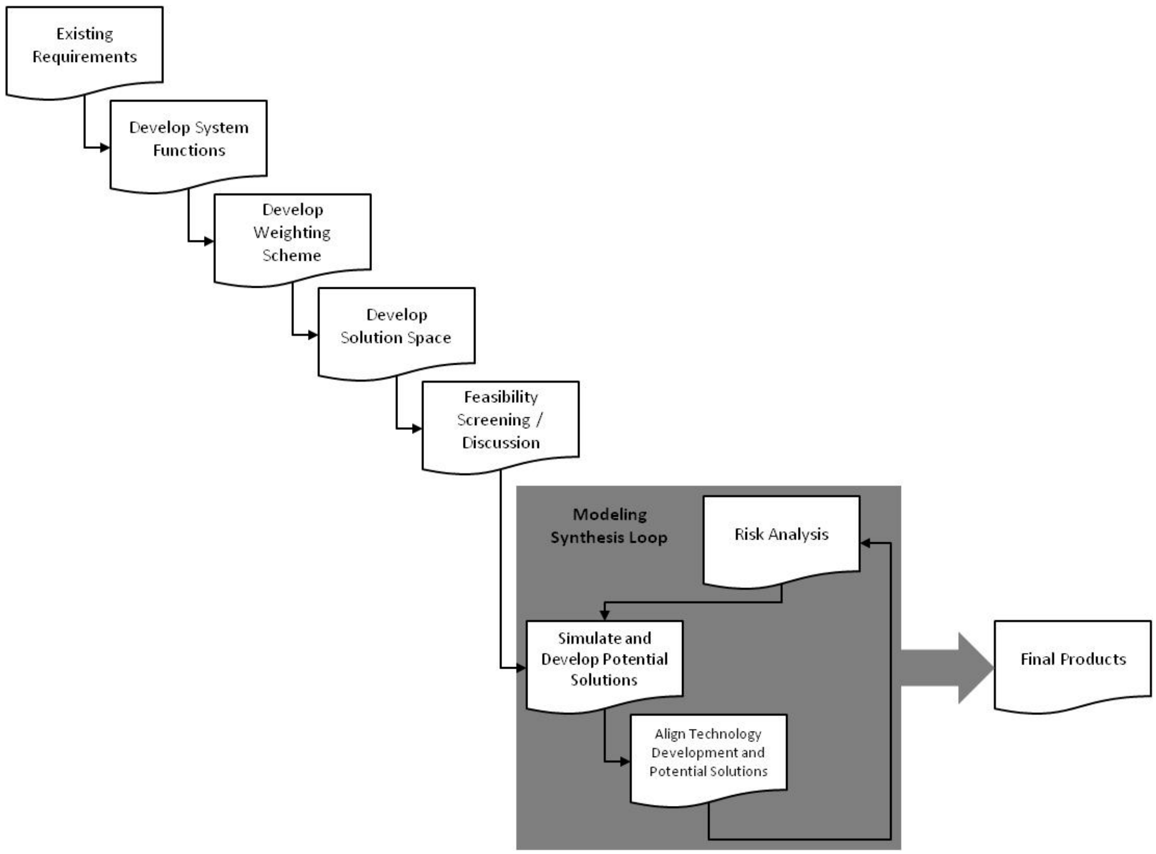

Figure 39. Methodology Flowchart Summary

The key part of the methodology used for the selection of candidate systems to recommend for further consideration is shown in the Modeling Synthesis Loop. Inputs into the loop include the user preferences in the form of preference weights, the threshold and objective values for the tradable requirements, and the "baseline" system (CLRF-IC), which was used as a starting point for system performance and weight. Inside the loop, available technologies were considered as an input into the model. The availability of technologies depend on the timeframe of the system under consideration (near, mid, and far-term) and also upon technology investment plans.

The model was run for different candidate physical configurations. The physics based model produced system performance values and also the predicted weight of the candidate system. These performance values were compared to the threshold and objective values, and using linear interpolation, a score for each requirement was generated. These scores were multiplied by the user preference based weights and summed to give a total score for the candidate system.

The strength of this model is that it allows for the comparison between various physical architectures within the requirements threshold and objective values. This permits easy analysis of "what if" scenarios such as determining whether pursuing an objective value is worthwhile when taking user preferences into consideration, and what the effect of different technologies are upon system performance. It is important to note that the user preference weights were static since they were determined before entering the modeling phase. The sensitivity of these values was explored in the Sensitivities to the Model section.

B. STUDY RESULTS

The capstone project team recommends that these results be used as a quantitative tool to assist a qualitative decision making process. The results should not be used directly as a recommendation of "this system is better than that" as there are many other things to consider before choosing a course of action. Additionally, there are limitations to the modeling that need to be considered.

1. Summary of Results

The results of the simulation and candidate system scoring are shown in Figure 40. The horizontal axis represents the year that the system would start production and the vertical axis represents the system score. For the mid-term and far-term systems, there are technologies included that are currently under development or under consideration.

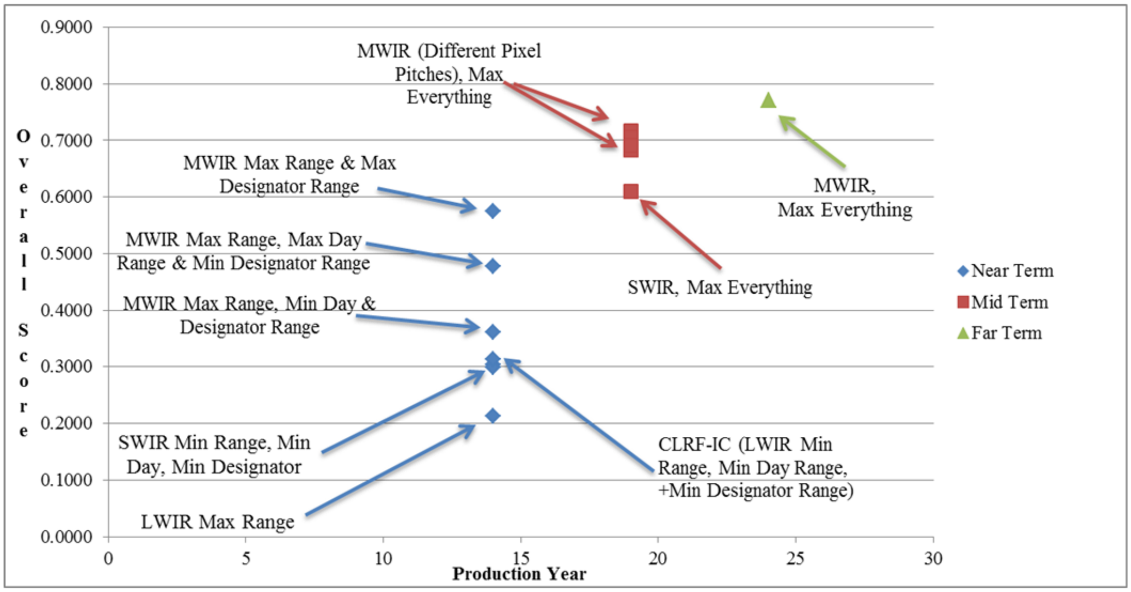

Figure 40. Candidate System Scoring Summary

The main system weight drivers were the night vision technology and the recognition range for night. Recognition range for day was not as much a weight driver. Azimuth sensor selection, which impacts TLE heavily, is also a system score driver. However, the major problem with azimuth sensors, other than the DMC, is a lack of full time availability and startup time. Therefore, much of the trade space involved trading off day and night recognition range, night vision technologies, and predicted technology improvements – but other trades were considered as well.

a. Near-Term Recommendations

The CLRF-IC baseline system is the third lowest scoring system in the near-term. Note that this isn't actually the CLRF-IC system, but a system based upon the CLRF-IC predicted performance plus addition of a designator module. A designator module will not be included in CLRF-IC because of the cost and because the JTAC-LTD designator was only recently procured and adding this to CLRF-IC would be redundant. CLRF-IC will likely include LWIR for night vision, the most affordable thermal imaging technology. It was also assumed that CLRF-IC would meet threshold values for the requirements and no more. CLRF-IC will not be capable of viewing laser spots in the nighttime, but may be capable of doing so in the daytime.

Increasing night vision range to the objective value actually decreased the total system score, due to the large aperture required to recognize targets at those ranges. This is a shortcoming of LWIR technology. Therefore, if LWIR is used, the recommendation is to meet only the threshold night recognition range requirement.

A CLRF-IC system was considered with a change of night vision technology to SWIR. This decreased the score slightly, but it was so small that it is considered to be equivalent to a CLRF-IC with LWIR technology. SWIR does have other advantages and disadvantages as discussed in the 1. Night Vision Technologies section, so it should be considered based upon the system score. However, SWIR technology is currently cost prohibitive for CLRF-IC.

It was discovered that meeting the maximum night recognition range with MWIR technology increased overall system score, which was the opposite of LWIR technology. Like LWIR, increasing recognition range increases system weight, but the increase is much less for MWIR. When combined with the user derived preference weights, the overall score increased. Like LWIR and SWIR, MWIR technology has other advantages and disadvantages that must be considered before choosing this technology. Like SWIR, MWIR is currently cost prohibitive for CLRF-IC.

Next, increasing day recognition range to the objective was explored. Again, this increased system weight but the overall score also increased. This is due to the fact that the day aperture is small to begin with and increasing it to meet the objective value doesn't add much system weight, which is offset by the day recognition range factor.

Finally, the designator range was increased to the objective value. This also increased the system score. The reason is the same as for day recognition range – the increase in aperture is small which leads to a small increase in weight, and when user preference weights are considered, the overall score increases.

The overall recommendations and benefits/limitations is shown later in Table 29. The ultimate choice depends not only on the overall score, but other tradeoffs such as cooldown time and other night vision technology tradeoffs.

b. Mid-Term Recommendations

The timeframe between near-term and mid-term systems will allow for the development of a new MEMS Inertial Azimuth Sensor, decreases in pixel sizes for imagers, and general weight reductions due to maturity of technologies including improved processor speeds.

Referring back to Figure 40, different pixel size reductions for MWIR were considered. Although this leads to a reduction in aperture size, and thus a decrease in weight, the overall effect on system score isn't significant. Therefore, the capstone project team does not recommend investing in reduction of MWIR pixel sizes.

SWIR technology with pixel size reductions was also considered. The best scoring system failed to outscore the lowest scoring MWIR system. Although the difference is significant, the capstone project team does not recommend abandoning SWIR technology as SWIR has advantages over MWIR and LWIR that should be considered.

Although not shown, LWIR technology was considered, but again the reduction in pixel size lead to an insignificant increase in system score over the CLRF-IC. When combined with the fact that LWIR cannot perform the LSI function, and therefore another system component would be required to do so, the LWIR technology was abandoned as MWIR clearly leads to a higher overall system score.

The addition of the new MEMS Inertial Azimuth Sensor does not improve the TLE accuracy, but does improve the availability of high accuracy over the celestial compass. This was not considered by the model, and, in fact, the increase in system weight decreases the overall system score. Fortunately, the new azimuth sensor is a lightweight component and the small increase in system weight doesn't skew the results.

The overall recommendations and benefits/limitations for the mid-term are shown in Table 29.

c. *Far-Term Recommendations*

The timeframe between mid-term and far-term systems allows for improvements in the accuracy of the MEMS Inertial Azimuth Sensor, further reductions in pixel sizes, and further reductions in component weights due to technology maturity.

Referring back to Figure 40, the lone system shown is the best of everything. It is a MWIR system with the minimum pixel size, the best azimuth sensors, technology maturity weight reductions, and it meets all the objective requirements. It does not outscore the best mid-term system by much. Therefore, the best recommendation is that it is not worthwhile to wait for the improvements offered over the mid-term. This does not include the possibility that significant cost reductions may be realized with maturing technology. Additionally, such long term predictions are notoriously hard to perform accurately. Therefore, the best thing to do is to revisit the analysis around the FY14 timeframe.

d. *Summary of Technical Recommendations*

A summary of the trade spaces as well as the benefits and limitations of those choices is shown in Table 29.

Table 29. Technical Recommendation Decision Matrix

		System Number	Score	Weight	Night Technology	Benefits & Limitations
Near-Term	Max Score	6.1	0.5742	6.35	MWIR	Meets Max Ranges for Day & Night Meets Max Designator Range LSI Capable **Requires Cooldown for MWIR Imager** **Heavy System**
	Min Weight	4	0.3141	4.75	MWIR	Meets Max Day Range **Min Night Range** LSI Capable **Requires Cooldown for MWIR Imager** Lowest Weight
	Lowest Cost*	1	0.3038	4.97	LWIR	**Min Day and Night Range** **Min Designator Range** **Not LSI Capable** Low Weight No Cooldown Required
Mid-Term	Max Score	7.2	0.7172	5.59	MWIR	Max Day and Night Range Max Designator Range LSI Capable **Cooldown Required**
	Min Weight	7.1	0.6092	5.55	MWIR	Max Day Range **Min Night Range** **Max Designator Range** LSI Capable **Cooldown Required**
	SWIR Alternative	8	0.6830	6.32	SWIR	Max Day and Night Range Max Designator Range LSI Capable Cooldown Required SWIR brings ability to see through windows **Moderately Heavier than MWIR Equivalent**
Far-Term	Have it All	10	0.7701	5.09	MWIR	Max Day and Night Range Max Designator Range LSI Capable **Cooldown Required**

A summary of specific technical recommendations follows:

1. MWIR and SWIR technologies should be seriously considered. Both of these technologies either match or exceed LWIR when both physical models and user preferences are considered. Both also allow for day and night LSI without additional components or additional weight.

2. Weight isn't king. Although weight is important (number two priority of users), increasing performance to the objective value actually increases overall system score. This was a surprise and is a key result. The lone exception is LWIR technology, which was covered by Recommendation #1.

3. Investment in pixel size reduction not worthwhile. The weight reduction for the JTAC suite isn't worth the investment effort. It may be worthwhile for aircraft or other systems which have much larger recognition requirements, but not for the JTAC suite.

4. Target Location Error Reduction is worth the investment. Although not covered by the model, when considering that it was the highest user priority and it had a 66% higher preference than the second highest priority (weight), it is clearly a key system function. ONR, the Army NVESD, and DARPA are investing heavily in new technologies to reduce TLE, and should continue to do so until TLE is reduced below 10m.

5. Investment in un-cooled SWIR may be worthwhile. ONR is investing heavily in the IDNST program with the goal to eliminate SWIR coolers and drive down SWIR cost. Elimination of the cooler will reduce system weight, reduce power consumption, reduce startup time, and increase overall system score. Other factors need to be considered when choosing between MWIR and SWIR that are beyond the scope of this capstone project.

6. Investment in un-cooled MWIR may be worthwhile. Although not being pursued by ONR or others, the trades between SWIR and MWIR need to be carefully considered. If MWIR is the desired technology, eliminating the cooler will reduce system weight, power consumption, and setup time.

2. Summary of Study Limitations

This study had a limited timeframe and was not funded by any agency. Therefore, a complete study of the trade spaces wasn't possible – some very notable exceptions are trades between night vision technologies, lack of consideration for startup time, lack of consideration of power consumption, and lack of consideration of the inability of celestial azimuth to provide solutions all the time.

The model was developed from equations found in the Army's NVThermIP and SSCamIP, but was a lower resolution. While the capstone project team owes a significant debt of gratitude to NVESD for their assistance with the modeling, the model developed wasn't validated/verified, nor is it anywhere near the sophistication of the Army models. For this reason, the capstone project team highly recommends that before any decisions are made, that the Army NVESD personnel are engaged to provide expert feedback on model results.

3. Life Cycle Cost Estimate Discussion

A Life Cycle Cost Estimate (LCCE) for the JTAC-SLM was not created due to the amount of information available during the project. The expected costs to procure future technologies that are not currently within development are often difficult to obtain as vendors tend to keep these costs within company proprietary information in order to remain competitive. This information was not available for an academic study, but might be able to be obtained in the future by MCSC for an actual program of record.

The remaining portions of the JTAC-SLM LCCE (i.e. personnel, training, maintenance, disposal, etc.) would be similar to currently fielded items and are understood costs within the JTAC community. The methodology to support and dispose of these systems is consistent with the current fielded systems and therefore these portions of the LCCE would be similar. An analysis on these costs was not included because it would not provide any additional information to the project.

C. STUDY METHODOLOGY

The capstone project team believes that the methodology used to develop the recommendations is just as important, if even not more important, than the recommendations of technologies. The process followed was covered in detail in previous sections and a condensed flowchart was shown in Figure 39.

The development of tradable requirements is key to the method. Tradable requirements meet two conditions. First, they are requirements which impact each other, usually in a negative way. For example, if recognition range increased (a desirable outcome), weight also increased (an undesirable outcome). Second, they have trade space – meaning that they have a threshold and objective environment. Just because a requirement isn't tradable, doesn't mean it isn't important. It just means that it doesn't meet the conditions. The development of tradable requirements allows for a simplification of the problem.

Engaging the users and incorporating their opinions and expertise is critically important to developing a satisfactory system in the opinion of the capstone project team. The users are the ones who have to use the system day in and day out, and they are the ones who understand the functions that the system must provide better than anyone. The method used for this study was to have the users evaluate the tradable requirements in a pairwise fashion through a survey. Because the number of tradable requirements is a subset (and therefore smaller) than the total number of requirements, the users are far more likely to complete the survey. For this study, thirty surveys were sent out and 27 contained complete responses – a success rate of 90%. Furthermore, by including tradable requirements only, the survey was limited to a single page and allowed the users to focus their efforts thus improving the quality of the information gathered as well. This user feedback was used to develop preference weights that were used in the model.

The modeling synthesis loop is similar to other methods and it works well. It allows for the inclusion of viable technologies, which in turn allows virtual system development and exploration of the impact of integrating new and improved technologies. This, in turn, provides input into technology prediction and planning, which is fed back into the model again.

The model itself is a two-step tool where the system performance parameters are developed using physics based modeling and build-up of system components, and the performance is then multiplied by the preference weights that were developed from the user surveys. The overall system "score" is a blend of the predicted system performance and the user preference weights. This provides a quantitative tool that can answer many hard questions, such as "The users want a light system, but they also want long target recognition ranges. Is the increase in weight worth the additional recognition range?". Historically, these sorts of questions are answered anecdotally – this tool allows them to be answered analytically.

V. SUMMARY AND CONCLUSIONS

A. SUMMARY OF WORK

This capstone project started during a meeting with the CD&I/MCCDC Capabilities Officer for the TACP suite of equipment. The Capability Officer provided the primitive need and guidance on the effective need. Requirements documents were then studied and the tradable requirements and inconsistencies within the requirements were determined. The CD&I/MCCDC Capabilities Officer for the TACP suite of equipment provided the threshold and objective values for the requirements. A one page user survey utilizing the pairwise comparison method was developed and was sent to users with combat experience. The MCSC Fire Support Systems SME sent out thirty surveys and received 27 back. User preference weights were developed from these surveys. Modeling information from Government contractors and the Army NVESD was gathered to develop a physics based performance model for the day and night optics and also the laser designator optics. Information on the anticipated component weights for the CLRF-IC was collected and used as a baseline for the model. Vendors provided individual component weights and technology trends – most did so anonymously. Plans from ONR on technology developments that support the TACP suite were gathered. The preference weights were combined with the projected system performance scores from the model to determine the overall system scores. A model was developed and iterated based on near, mid, and far-term acquisition of the TACP targeting system, now called JTAC-SLM. This led to the discovery of system score drivers and the development of a TRMP for targeting technologies. This plan is included in MCSC's overall Modernization Plan which is being published and will be available to ONR, CD&I/MCCDC, DoD Contractors, and other DoD agencies. Specific recommendations for JTAC-SLM were provided and recommendations for the adoption of the methodology as a tool for the development of other systems beyond the TACP suite of equipment were made.

B. ANSWERS TO RESEARCH QUESTIONS

- What are the current requirements for the individual pieces of equipment in the TACP suite of equipment?

  This was covered in the Requirements section. (Page 20)

- What are the key performance requirements for the individual pieces of equipment in the TACP suite of equipment?

  The key requirements are found in Table 7. (Page 23)

- What are acceptable areas of trade-off between the key performance requirements?

  The acceptable areas of tradeoff were the threshold and objective values discovered during the research of existing requirements documents and further refined by CD&I/MCCDC. They can be found in Table 7. (Page 23)

- What are the interrelationships between the key performance requirements?

  The areas of tradeoff are day and night recognition range vs. weight, TLE vs. weight, and laser designation range vs. weight. These were modeled extensively and were covered in the Simulate and Develop Potential Solutions section. (Page 44)

- What would potential systems "look like" while varying certain key performance requirements within the trade space?

  These were modeled and were scored by including the preference weights provided by the user surveys. A summary can be found in Figure 40. (Page 110)

- What S&T efforts, ongoing and planned, can be utilized to realize the potential systems?

The S&T efforts that support this capstone project are detailed in the TRMP section. (Page 82)

- How can these systems be realized utilizing a TRMP?

  This was answered by developing the TRMP and can be found in the TRMP section. (Page 82)

- What are the functions that the TACP users are expected to perform with the TACP suite of equipment?

  A summary of the functions can be found in the Develop System Functions section. (Page 34)

- What are the areas of overlap or conflict within the TACP suite of equipment and the TACP user functions?

  These areas of overlap were identified as part of the requirements analysis beginning in the Requirements section. (Page 20)

- What are the risks associated with developing the potential systems?

  A complete risk analysis can be found in TRMP section under Risk Analysis. (Page 82)

C. SUMMARY OF TECHNICAL RECOMMENDATIONS

The capstone project team believes that the recommendations provided in this report should be used as input into decisions on how to develop the TACP suite of equipment and not used as specific recommendations to make decisions. Some other important trades were not studied and the model was not validated/verified by an independent source. If these recommendations are utilized, the capstone project team strongly recommends utilizing the Army NVESD for optics and laser performance prediction and including a trade of the advantages/disadvantages of SWIR, MWIR, and LWIR night vision technologies.

It is commonly believed that weight is the most important requirement for handheld targeting systems. The user feedback collected during this study contradicts this belief. It turns out that weight comes in second on the requirements list, behind TLE. The reason for this is because the user community recognizes the tactical advantage of a first round strike. These same users are well aware that they are not able to call for GPS guided munitions at all if the CLRF is the only source of targeting information. This reality limited the ability to utilize these highly effective weapons in combat and the users are highly dissatisfied with this situation.

The ongoing development of precision azimuth sensors—the key component required to improve TLE—is well worth the investment. ONR has been, and continues to be, encouraged to develop the MEMS Inertial Azimuth Sensor and also support incremental improvements to the Celestial Compass. These two technologies complement each other. Celestial compasses work nearly instantly when they have a clear view of the sun or stars but don't work under cloud cover or canopy. The MEMS Inertial Azimuth Sensor will work all the time, but will require fifteen seconds to provide a low quality solution and upwards of two minutes to provide a precision solution. Both technologies are small and light enough to include in future systems. Celestial compasses are currently affordable and will become even cheaper, while the MEMS Inertial Azimuth Sensor is based on silicon wafer technology and should be very low cost.

Investment in low cost, un-cooled SWIR technology may be worthwhile for the TACP suite. Investment in a low cost MWIR technology also looks promising, but with the caveat that night vision technology needs further study before any decisions are made.

D. SUMMARY OF METHODOLOGY RECOMMENDATIONS

The capstone project team strongly believes that the method used to develop the recommendations is sound and provides value beyond the current TACP suite of equipment and targeting systems in general. The method allows for the reduction of the study space by reducing the requirement set to those which are tradable. These tradable requirements allow for the development of a short and intuitive pairwise comparison survey that has a high rate of return and provides high value information directly from the very users who will use the systems on a regular basis. By incorporating "the voice of the user" directly in the system performance model, various "what if" sorts of comparisons can be accomplished very quickly, exposing areas that are worthy of further study. The modeling synthesis loop allows for consideration of future technologies, and also permits the model output to drive the search for new technologies.

The TRMP developed as part of this report is a key product—it will be included in MCSC's overall Modernization Plan.

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VI. APPENDIX A – USER SURVEY

This Appendix contains the user survey, shown in Figure 41, which was developed in order to receive critical information from the actual JTAC users for performing the requirements analysis. Note that the user survey contained two additional requirements not considered within the capstone project analysis (both of the Laser Imaging Range requirements). The reason for this is because these two requirements were determined to not have an effect on the modeling effort due to limitations within technology. The technology that is utilized to meet these requirements produces a given capability at a given weight. Therefore the requirements were removed and only the pertinent information was utilized from the user survey.

JTAC/FAC/FO User Survey

Thank you for taking the time to fill out this user survey on the TACP suite. It should take you about 10 minutes to complete. The goal of this survey is to get preference data from Marines that use these systems so that future requirements of these systems can be steered to meet your needs.

Instructions:
Please provide the personnel information prior to filling out the table. Following the personnel information, seven different system attributes are presented in the table below for you to rank. One of the attributes (weight) is repeated six times on the left hand side and will be compared to the six different attributes on the right hand side. For each of the six pairs, please place an "X" in the box that you feel is correct. Only one "X" should be used for each pair. If you feel the two attributes are equally important, an "X" should go in the "Equivalent" column. If you feel that weight is more important, an "X" should go in one of the green columns. If you feel that the attribute being compared against weight is more important, an "X" should go in one of the red columns.

Rank:
MOS:
Current Duty Station:
What experience do you have with using items from the TACP suite?

System Attribute	Much More Important	More Important	Slightly More Important	Equivalent	Slightly More Important	More Important	Much More Important	System Attribute
Weight								Recognition Range (Day)
Weight								Recognition Range (Night)
Weight								Laser Imaging Range (Day)
Weight								Laser Imaging Range (Night)
Weight								Target Location Error
Weight								Designation Range

Attribute Definitions:
Weight – The weight of the entire handheld system (does not include carry case, tripod, spare batteries, and other ancillary items).
Recognition Range (Day) – The distance during daylight conditions at which the type of a target can be determined, i.e. tracked vs. wheeled vehicle.
Recognition Range (Night) – The distance during night conditions at which the type of a target can be determined, i.e. tracked vs. wheeled vehicle.
Laser Imaging Range (Day) – The distance during daylight conditions at which the designator (1064 nm) laser spot can be seen on a target.
Laser Imaging Range (Night) – The distance during night conditions at which the designator (1064 nm) laser spot can be seen on a target.
Target Location Error – The difference between coordinates generated for a target and the actual location of the target.
Designation Range – The distance between the hand held designator operator and the marked target.

Figure 41. JTAC-SLM User Survey

VII. APPENDIX B – MODEL SIMULATIONS

This Appendix contains figures of all the model simulations for the near, mid, and far-term systems, that were developed during this capstone project.

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY14	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000		0 to 10,000 m
Recognition Range - Night (m)	900		0 to 10,000 m
Designation Range (m)	2,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code			
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.77	N/A	Calculated
Pixel Angular Size (urads)	191.67	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Given
Weight of System Optics (g)	86.77	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	900	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	LWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	1.200		1.0 to 1.2
f/# Hard Code			
Wavelength (µm)	10.000		8 to 14 µm
Target Angular Size (mrads)	2.56	N/A	Calculated
Pixel Angular Size (urads)	161.95	N/A	Calculated
Q	0.71	N/A	Calculated
Aperture Diameter Size (mm)	87.48	N/A	Calculated

Figure 42. Near System 1 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	87.48	N/A	Given
Weight of System Optics (g)	262.59	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	5.0		1 to 20 mil
Theta (rad)	0.0049	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	19.63	N/A	Calculated
Sigma X (m)	20.26	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	15.36	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	1.00		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	88.3	N/A	Calculated
MicroElectroMechanical Systems Included	No	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	0.0	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	1.00		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	500.0	N/A	Calculated
Designation Range (m)	2,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	23.0	N/A	Calculated

Figure 43. Near System 1 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	1.00		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	84.6	N/A	Calculated
Electronics Improvement Factor	1.00		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	152.5	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	1.00		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	61.2	N/A	Calculated
Battery Improvement Factor	1.00		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	124.3	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	86.8	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	0.0	N/A	Given
Night Imager Lens Weight (g)	262.6	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	88.3	N/A	Given
MEMS Weight (g)	0.0	N/A	Given
Designator Module Weight (g)	500.0	N/A	Given
Designator Optics Weight (g)	23.0	N/A	Given
LRF Weight (g)	84.6	N/A	Given
Electronics Weight (g)	152.5	N/A	Given
GPS Weight (g)	61.2	N/A	Given
Battery Weight (g)	124.3	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	650.9	N/A	Calculated
Total Weight (g)	2,252.3	N/A	Calculated
Total Weight (lbs)	4.97	N/A	Calculated

Figure 44. Near System 1 Results (Part 3)

Overall Preference		0.3038
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	4.97
	Normalized Preference	0.5780
	Calculated Weight	0.2489
	Weighted Preference	0.1439
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	3,000
	Normalized Preference	0.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0000
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	900
	Normalized Preference	0.0000
	Calculated Weight	0.1102
	Weighted Preference	0.0000
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	15
	Normalized Preference	0.3856
	Calculated Weight	0.4148
	Weighted Preference	0.1599
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	2,000
	Normalized Preference	0.0000
	Calculated Weight	0.1461
	Weighted Preference	0.0000

Figure 45. Near System 1 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY14	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000		0 to 10,000 m
Recognition Range - Night (m)	1,675		0 to 10,000 m
Designation Range (m)	2,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	-		
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.77	N/A	Calculated
Pixel Angular Size (urads)	191.67	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Given
Weight of System Optics (g)	86.77	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	1,675	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	LWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	1.200		1.0 to 1.2
f/# Hard Code			
Wavelength (µm)	10.000		8 to 14 µm
Target Angular Size (mrads)	1.37	N/A	Calculated
Pixel Angular Size (urads)	87.02	N/A	Calculated
Q	0.71	N/A	Calculated
Aperture Diameter Size (mm)	162.80	N/A	Calculated

Figure 46. Near System 2 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	162.80	N/A	Given
Weight of System Optics (g)	1,240.82	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	5.0		1 to 20 mil
Theta (rad)	0.0049	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	19.63	N/A	Calculated
Sigma X (m)	20.26	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	15.36	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	1.00		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	88.3	N/A	Calculated
MicroElectroMechanical Systems Included	No	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	0.0	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	1.00		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	500.0	N/A	Calculated
Designation Range (m)	2,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	23.0	N/A	Calculated

Figure 47. Near System 2 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	1.00		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	84.6	N/A	Calculated
Electronics Improvement Factor	1.00		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	152.5	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	1.00		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	61.2	N/A	Calculated
Battery Improvement Factor	1.00		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	124.3	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	86.8	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	0.0	N/A	Given
Night Imager Lens Weight (g)	1,240.8	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	88.3	N/A	Given
MEMS Weight (g)	0.0	N/A	Given
Designator Module Weight (g)	500.0	N/A	Given
Designator Optics Weight (g)	23.0	N/A	Given
LRF Weight (g)	84.6	N/A	Given
Electronics Weight (g)	152.5	N/A	Given
GPS Weight (g)	61.2	N/A	Given
Battery Weight (g)	124.3	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	1,048.5	N/A	Calculated
Total Weight (g)	3,628.2	N/A	Calculated
Total Weight (lbs)	8.00	N/A	Calculated

Figure 48. Near System 2 Results (Part 3)

Overall Preference		0.2134
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	8.00
	Normalized Preference	0.0002
	Calculated Weight	0.2489
	Weighted Preference	0.0001
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	3,000
	Normalized Preference	0.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0000
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	1,675
	Normalized Preference	0.4844
	Calculated Weight	0.1102
	Weighted Preference	0.0534
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	15
	Normalized Preference	0.3856
	Calculated Weight	0.4148
	Weighted Preference	0.1599
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	2,000
	Normalized Preference	0.0000
	Calculated Weight	0.1461
	Weighted Preference	0.0000

Figure 49. Near System 2 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY14	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000		0 to 10,000 m
Recognition Range - Night (m)	900		0 to 10,000 m
Designation Range (m)	2,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	.		
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.77	N/A	Calculated
Pixel Angular Size (urads)	191.67	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Given
Weight of System Optics (g)	86.77	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	900	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (µm)	12.00		2.2 to 25 µm
Technology Type	SWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	1.200		1 to 2
f/# Hard Code			
Wavelength (µm)	1.667		1 to 3 µm
Target Angular Size (mrads)	2.56	N/A	Calculated
Pixel Angular Size (urads)	161.95	N/A	Calculated
Q	0.17	N/A	Calculated
Aperture Diameter Size (mm)	61.75	N/A	Calculated

Figure 50. Near System 3 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	61.75	N/A	Given
Weight of System Optics (g)	109.93	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	5.0		1 to 20 mil
Theta (rad)	0.0049	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	19.63	N/A	Calculated
Sigma X (m)	20.26	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	15.36	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	1.00		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	88.3	N/A	Calculated
MicroElectroMechanical Systems Included	No	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	0.0	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	1.00		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	500.0	N/A	Calculated
Designation Range (m)	2,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	23.0	N/A	Calculated

Figure 51. Near System 3 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	1.00		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	84.6	N/A	Calculated
Electronics Improvement Factor	1.00		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	152.5	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	1.00		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	61.2	N/A	Calculated
Battery Improvement Factor	1.00		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	124.3	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	86.8	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	109.9	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	88.3	N/A	Given
MEMS Weight (g)	0.0	N/A	Given
Designator Module Weight (g)	500.0	N/A	Given
Designator Optics Weight (g)	23.0	N/A	Given
LRF Weight (g)	84.6	N/A	Given
Electronics Weight (g)	152.5	N/A	Given
GPS Weight (g)	61.2	N/A	Given
Battery Weight (g)	124.3	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	664.1	N/A	Calculated
Total Weight (g)	2,297.8	N/A	Calculated
Total Weight (lbs)	5.1	N/A	Calculated

Figure 52. Near System 3 Results (Part 3)

Overall Preference		0.2991
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	5.07
	Normalized Preference	0.5589
	Calculated Weight	0.2489
	Weighted Preference	0.1391
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	3,000
	Normalized Preference	0.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0000
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	900
	Normalized Preference	0.0000
	Calculated Weight	0.1102
	Weighted Preference	0.0000
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	15
	Normalized Preference	0.3856
	Calculated Weight	0.4148
	Weighted Preference	0.1599
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	2,000
	Normalized Preference	0.0000
	Calculated Weight	0.1461
	Weighted Preference	0.0000

Figure 53. Near System 3 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY14	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000		0 to 10,000 m
Recognition Range - Night (m)	900		0 to 10,000 m
Designation Range (m)	2,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	3,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (μm)	17.00		2.2 to 25 μm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code			
Wavelength (μm)	0.598		0.35 to 0.74 μm
Target Angular Size (mrads)	0.77	N/A	Calculated
Pixel Angular Size (urads)	191.67	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	29.57	N/A	Given
Weight of System Optics (g)	86.77	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	900	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (μm)	12.00		2.2 to 25 μm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (μm)	3.667		3 to 5 μm
Target Angular Size (mrads)	2.56	N/A	Calculated
Pixel Angular Size (urads)	161.95	N/A	Calculated
Q	1.07	N/A	Calculated
Aperture Diameter Size (mm)	21.17	N/A	Calculated

Figure 54. Near System 4 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	21.17	N/A	Given
Weight of System Optics (g)	7.57	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	5.0		1 to 20 mil
Theta (rad)	0.0049	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	19.63	N/A	Calculated
Sigma X (m)	20.26	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	15.36	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	1.00		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	88.3	N/A	Calculated
MicroElectroMechanical Systems Included	No	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	0.0	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	1.00		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	500.0	N/A	Calculated
Designation Range (m)	2,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	23.0	N/A	Calculated

Figure 55. Near System 4 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	1.00		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	84.6	N/A	Calculated
Electronics Improvement Factor	1.00		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	152.5	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	1.00		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	61.2	N/A	Calculated
Battery Improvement Factor	1.00		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	124.3	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	86.8	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	7.6	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	88.3	N/A	Given
MEMS Weight (g)	0.0	N/A	Given
Designator Module Weight (g)	500.0	N/A	Given
Designator Optics Weight (g)	23.0	N/A	Given
LRF Weight (g)	84.6	N/A	Given
Electronics Weight (g)	152.5	N/A	Given
GPS Weight (g)	61.2	N/A	Given
Battery Weight (g)	124.3	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	622.5	N/A	Calculated
Total Weight (g)	2,153.9	N/A	Calculated
Total Weight (lbs)	4.7	N/A	Calculated

Figure 56. Near System 4 Results (Part 3)

Overall Preference		0.3141
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	4.75
	Normalized Preference	0.6193
	Calculated Weight	0.2489
	Weighted Preference	0.1542
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	3,000
	Normalized Preference	0.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0000
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	900
	Normalized Preference	0.0000
	Calculated Weight	0.1102
	Weighted Preference	0.0000
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	15
	Normalized Preference	0.3856
	Calculated Weight	0.4148
	Weighted Preference	0.1599
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	2,000
	Normalized Preference	0.0000
	Calculated Weight	0.1461
	Weighted Preference	0.0000

Figure 57. Near System 4 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY14	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	900		0 to 10,000 m
Designation Range (m)	2,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (μm)	17.00		2.2 to 25 μm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	.		
Wavelength (μm)	0.598		0.35 to 0.74 μm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	900	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (μm)	12.00		2.2 to 25 μm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (μm)	3.667		3 to 5 μm
Target Angular Size (mrads)	2.56	N/A	Calculated
Pixel Angular Size (urads)	161.95	N/A	Calculated
Q	1.07	N/A	Calculated
Aperture Diameter Size (mm)	21.17	N/A	Calculated

Figure 58. Near System 5 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	21.17	N/A	Given
Weight of System Optics (g)	7.57	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	5.0		1 to 20 mil
Theta (rad)	0.0049	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	19.63	N/A	Calculated
Sigma X (m)	20.26	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	15.36	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	1.00		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	88.3	N/A	Calculated
MicroElectroMechanical Systems Included	No	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	0.0	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	1.00		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	500.0	N/A	Calculated
Designation Range (m)	2,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	23.0	N/A	Calculated

Figure 59. Near System 5 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	1.00		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	84.6	N/A	Calculated
Electronics Improvement Factor	1.00		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	152.5	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	1.00		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	61.2	N/A	Calculated
Battery Improvement Factor	1.00		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	124.3	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	7.6	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	88.3	N/A	Given
MEMS Weight (g)	0.0	N/A	Given
Designator Module Weight (g)	500.0	N/A	Given
Designator Optics Weight (g)	23.0	N/A	Given
LRF Weight (g)	84.6	N/A	Given
Electronics Weight (g)	152.5	N/A	Given
GPS Weight (g)	61.2	N/A	Given
Battery Weight (g)	124.3	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	713.7	N/A	Calculated
Total Weight (g)	2,469.5	N/A	Calculated
Total Weight (lbs)	5.4	N/A	Calculated

Figure 60. Near System 5 Results (Part 3)

Overall Preference		0.3611
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	5.44
	Normalized Preference	0.4868
	Calculated Weight	0.2489
	Weighted Preference	0.1212
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	900
	Normalized Preference	0.0000
	Calculated Weight	0.1102
	Weighted Preference	0.0000
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	15
	Normalized Preference	0.3856
	Calculated Weight	0.4148
	Weighted Preference	0.1599
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	2,000
	Normalized Preference	0.0000
	Calculated Weight	0.1461
	Weighted Preference	0.0000

Figure 61. Near System 5 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY14	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	900		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (μm)	17.00		2.2 to 25 μm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	.		
Wavelength (μm)	0.598		0.35 to 0.74 μm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	900	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (μm)	12.00		2.2 to 25 μm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (μm)	3.667		3 to 5 μm
Target Angular Size (mrads)	2.56	N/A	Calculated
Pixel Angular Size (urads)	161.95	N/A	Calculated
Q	1.07	N/A	Calculated
Aperture Diameter Size (mm)	21.17	N/A	Calculated

Figure 62. Near System 6 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	21.17	N/A	Given
Weight of System Optics (g)	7.57	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	5.0		1 to 20 mil
Theta (rad)	0.0049	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	19.63	N/A	Calculated
Sigma X (m)	20.26	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	15.36	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	1.00		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	88.3	N/A	Calculated
MicroElectroMechanical Systems Included	No	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	0.0	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	1.00		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	500.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 63. Near System 6 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	1.00		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	84.6	N/A	Calculated
Electronics Improvement Factor	1.00		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	152.5	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	1.00		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	61.2	N/A	Calculated
Battery Improvement Factor	1.00		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	124.3	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	7.6	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	88.3	N/A	Given
MEMS Weight (g)	0.0	N/A	Given
Designator Module Weight (g)	500.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	84.6	N/A	Given
Electronics Weight (g)	152.5	N/A	Given
GPS Weight (g)	61.2	N/A	Given
Battery Weight (g)	124.3	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	796.5	N/A	Calculated
Total Weight (g)	2,756.2	N/A	Calculated
Total Weight (lbs)	6.1	N/A	Calculated

Figure 64. Near System 6 Results (Part 3)

Overall Preference		0.4772
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	6.08
	Normalized Preference	0.3664
	Calculated Weight	0.2489
	Weighted Preference	0.0912
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	900
	Normalized Preference	0.0000
	Calculated Weight	0.1102
	Weighted Preference	0.0000
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	15
	Normalized Preference	0.3856
	Calculated Weight	0.4148
	Weighted Preference	0.1599
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 65. Near System 6 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY14	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	2,500		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (μm)	17.00		2.2 to 25 μm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	.		
Wavelength (μm)	0.598		0.35 to 0.74 μm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	2,500	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (μm)	12.00		2.2 to 25 μm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (μm)	3.667		3 to 5 μm
Target Angular Size (mrads)	0.92	N/A	Calculated
Pixel Angular Size (urads)	58.30	N/A	Calculated
Q	1.07	N/A	Calculated
Aperture Diameter Size (mm)	58.81	N/A	Calculated

Figure 66. Near System 6.1 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	58.81	N/A	Given
Weight of System Optics (g)	97.31	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	5.0		1 to 20 mil
Theta (rad)	0.0049	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	19.63	N/A	Calculated
Sigma X (m)	20.26	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	15.36	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	1.00		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	88.3	N/A	Calculated
MicroElectroMechanical Systems Included	No	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	0.0	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	1.00		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	500.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 67. Near System 6.1 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	1.00		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	84.6	N/A	Calculated
Electronics Improvement Factor	1.00		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	152.5	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	1.00		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	61.2	N/A	Calculated
Battery Improvement Factor	1.00		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	124.3	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	97.3	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	88.3	N/A	Given
MEMS Weight (g)	0.0	N/A	Given
Designator Module Weight (g)	500.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	84.6	N/A	Given
Electronics Weight (g)	152.5	N/A	Given
GPS Weight (g)	61.2	N/A	Given
Battery Weight (g)	124.3	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	833.0	N/A	Calculated
Total Weight (g)	2,882.4	N/A	Calculated
Total Weight (lbs)	6.4	N/A	Calculated

Figure 68. Near System 6.1 Results (Part 3)

Overall Preference		0.5742
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	6.35
	Normalized Preference	0.3134
	Calculated Weight	0.2489
	Weighted Preference	0.0780
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	2,500
	Normalized Preference	1.0000
	Calculated Weight	0.1102
	Weighted Preference	0.1102
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	15
	Normalized Preference	0.3856
	Calculated Weight	0.4148
	Weighted Preference	0.1599
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 69. Near System 6.1 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY19	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	2,500		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (μm)	17.00		2.2 to 25 μm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code			
Wavelength (μm)	0.598		0.35 to 0.74 μm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	2,500	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (μm)	8.00		2.2 to 25 μm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (μm)	3.667		3 to 5 μm
Target Angular Size (mrads)	0.92	N/A	Calculated
Pixel Angular Size (urads)	58.30	N/A	Calculated
Q	1.60	N/A	Calculated
Aperture Diameter Size (mm)	39.20	N/A	Calculated

Figure 70. Mid System 7 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	39.20	N/A	Given
Weight of System Optics (g)	35.31	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	2.0		1 to 20 mil
Theta (rad)	0.0020	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	7.85	N/A	Calculated
Sigma X (m)	9.31	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	8.91	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	0.67		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	59.2	N/A	Calculated
MicroElectroMechanical Systems Included	Yes	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	113.6	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	0.67		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	335.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 71. Mid System 7 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	0.80		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	67.7	N/A	Calculated
Electronics Improvement Factor	0.80		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	122.0	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	0.80		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	49.0	N/A	Calculated
Battery Improvement Factor	0.80		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	99.4	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	35.3	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	59.2	N/A	Given
MEMS Weight (g)	113.6	N/A	Given
Designator Module Weight (g)	335.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	67.7	N/A	Given
Electronics Weight (g)	122.0	N/A	Given
GPS Weight (g)	49.0	N/A	Given
Battery Weight (g)	99.4	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	740.7	N/A	Calculated
Total Weight (g)	2,563.1	N/A	Calculated
Total Weight (lbs)	5.7	N/A	Calculated

Figure 72. Mid System 7 Results (Part 3)

Overall Preference		0.7146
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	5.65
	Normalized Preference	0.4475
	Calculated Weight	0.2489
	Weighted Preference	0.1114
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	2,500
	Normalized Preference	1.0000
	Calculated Weight	0.1102
	Weighted Preference	0.1102
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	9
	Normalized Preference	0.6434
	Calculated Weight	0.4148
	Weighted Preference	0.2669
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 73. Mid System 7 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY19	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	900		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code			
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	900	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (µm)	8.00		2.2 to 25 µm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (µm)	3.667		3 to 5 µm
Target Angular Size (mrads)	2.56	N/A	Calculated
Pixel Angular Size (urads)	161.95	N/A	Calculated
Q	1.60	N/A	Calculated
Aperture Diameter Size (mm)	14.11	N/A	Calculated

Figure 74. Mid System 7.1 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	14.11	N/A	Given
Weight of System Optics (g)	2.75	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	2.0		1 to 20 mil
Theta (rad)	0.0020	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	7.85	N/A	Calculated
Sigma X (m)	9.31	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	8.91	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	0.67		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	59.2	N/A	Calculated
MicroElectroMechanical Systems Included	Yes	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	113.6	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	0.67		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	335.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 75. Mid System 7.1 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	0.80		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	67.7	N/A	Calculated
Electronics Improvement Factor	0.80		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	122.0	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	0.80		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	49.0	N/A	Calculated
Battery Improvement Factor	0.80		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	99.4	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	2.7	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	59.2	N/A	Given
MEMS Weight (g)	113.6	N/A	Given
Designator Module Weight (g)	335.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	67.7	N/A	Given
Electronics Weight (g)	122.0	N/A	Given
GPS Weight (g)	49.0	N/A	Given
Battery Weight (g)	99.4	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	727.5	N/A	Calculated
Total Weight (g)	2,517.3	N/A	Calculated
Total Weight (lbs)	5.5	N/A	Calculated

Figure 76. Mid System 7.1 Results (Part 3)

Overall Preference		0.6092
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	5.55
	Normalized Preference	0.4667
	Calculated Weight	0.2489
	Weighted Preference	0.1162
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	900
	Normalized Preference	0.0000
	Calculated Weight	0.1102
	Weighted Preference	0.0000
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	9
	Normalized Preference	0.6434
	Calculated Weight	0.4148
	Weighted Preference	0.2669
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 77. Mid System 7.1 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY19	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	2,500		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	.		
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	2,500	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (µm)	6.00		2.2 to 25 µm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (µm)	3.667		3 to 5 µm
Target Angular Size (mrads)	0.92	N/A	Calculated
Pixel Angular Size (urads)	58.30	N/A	Calculated
Q	2.14	N/A	Calculated
Aperture Diameter Size (mm)	29.40	N/A	Calculated

Figure 78. Mid System 7.2 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	29.40	N/A	Given
Weight of System Optics (g)	17.20	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	2.0		1 to 20 mil
Theta (rad)	0.0020	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	7.85	N/A	Calculated
Sigma X (m)	9.31	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	8.91	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	0.67		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	59.2	N/A	Calculated
MicroElectroMechanical Systems Included	Yes	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	113.6	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	0.67		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	335.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 79. Mid System 7.2 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	0.80		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	67.7	N/A	Calculated
Electronics Improvement Factor	0.80		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	122.0	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	0.80		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	49.0	N/A	Calculated
Battery Improvement Factor	0.80		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	99.4	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	17.2	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	59.2	N/A	Given
MEMS Weight (g)	113.6	N/A	Given
Designator Module Weight (g)	335.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	67.7	N/A	Given
Electronics Weight (g)	122.0	N/A	Given
GPS Weight (g)	49.0	N/A	Given
Battery Weight (g)	99.4	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	733.4	N/A	Calculated
Total Weight (g)	2,537.6	N/A	Calculated
Total Weight (lbs)	5.6	N/A	Calculated

Figure 80. Mid System 7.2 Results (Part 3)

Overall Preference		0.7172
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	5.59
	Normalized Preference	0.4582
	Calculated Weight	0.2489
	Weighted Preference	0.1140
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	2,500
	Normalized Preference	1.0000
	Calculated Weight	0.1102
	Weighted Preference	0.1102
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	9
	Normalized Preference	0.6434
	Calculated Weight	0.4148
	Weighted Preference	0.2669
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 81. Mid System 7.2 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY19	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	2,500		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	.		
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	2,500	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (µm)	12.00		2.2 to 25 µm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (µm)	3.667		3 to 5 µm
Target Angular Size (mrads)	0.92	N/A	Calculated
Pixel Angular Size (urads)	58.30	N/A	Calculated
Q	1.07	N/A	Calculated
Aperture Diameter Size (mm)	58.81	N/A	Calculated

Figure 82. Mid System 7.3 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	58.81	N/A	Given
Weight of System Optics (g)	97.31	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	2.0		1 to 20 mil
Theta (rad)	0.0020	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	7.85	N/A	Calculated
Sigma X (m)	9.31	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	8.91	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	0.67		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	59.2	N/A	Calculated
MicroElectroMechanical Systems Included	Yes	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	113.6	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	0.67		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	335.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 83. Mid System 7.3 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	0.80		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	67.7	N/A	Calculated
Electronics Improvement Factor	0.80		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	122.0	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	0.80		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	49.0	N/A	Calculated
Battery Improvement Factor	0.80		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	99.4	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	97.3	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	59.2	N/A	Given
MEMS Weight (g)	113.6	N/A	Given
Designator Module Weight (g)	335.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	67.7	N/A	Given
Electronics Weight (g)	122.0	N/A	Given
GPS Weight (g)	49.0	N/A	Given
Battery Weight (g)	99.4	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	765.9	N/A	Calculated
Total Weight (g)	2,650.3	N/A	Calculated
Total Weight (lbs)	5.8	N/A	Calculated

Figure 84. Mid System 7.3 Results (Part 3)

Overall Preference		0.7055
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	5.84
	Normalized Preference	0.4109
	Calculated Weight	0.2489
	Weighted Preference	0.1023
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	2,500
	Normalized Preference	1.0000
	Calculated Weight	0.1102
	Weighted Preference	0.1102
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	9
	Normalized Preference	0.6434
	Calculated Weight	0.4148
	Weighted Preference	0.2669
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 85. Mid System 7.3 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY19	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	2,500		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code			
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	2,500	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (µm)	6.00		2.2 to 25 µm
Technology Type	SWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	1.200		1 to 2
f/# Hard Code			
Wavelength (µm)	1.667		1 to 3 µm
Target Angular Size (mrads)	0.92	N/A	Calculated
Pixel Angular Size (urads)	58.30	N/A	Calculated
Q	0.33	N/A	Calculated
Aperture Diameter Size (mm)	85.76	N/A	Calculated

Figure 86. Mid System 8 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	85.76	N/A	Given
Weight of System Optics (g)	249.91	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	2.0		1 to 20 mil
Theta (rad)	0.0020	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	7.85	N/A	Calculated
Sigma X (m)	9.31	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	8.91	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	0.67		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	59.2	N/A	Calculated
MicroElectroMechanical Systems Included	Yes	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	113.6	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	0.67		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	335.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 87. Mid System 8 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	0.80		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	67.7	N/A	Calculated
Electronics Improvement Factor	0.80		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	122.0	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	0.80		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	49.0	N/A	Calculated
Battery Improvement Factor	0.80		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	99.4	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	249.9	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	59.2	N/A	Given
MEMS Weight (g)	113.6	N/A	Given
Designator Module Weight (g)	335.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	67.7	N/A	Given
Electronics Weight (g)	122.0	N/A	Given
GPS Weight (g)	49.0	N/A	Given
Battery Weight (g)	99.4	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	828.0	N/A	Calculated
Total Weight (g)	2,864.9	N/A	Calculated
Total Weight (lbs)	6.3	N/A	Calculated

Figure 88. Mid System 8 Results (Part 3)

Overall Preference		0.6830
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	6.32
	Normalized Preference	0.3208
	Calculated Weight	0.2489
	Weighted Preference	0.0798
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	2,500
	Normalized Preference	1.0000
	Calculated Weight	0.1102
	Weighted Preference	0.1102
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	9
	Normalized Preference	0.6434
	Calculated Weight	0.4148
	Weighted Preference	0.2669
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 89. Mid System 8 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY19	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	5,000		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (µm)	17.00		2.2 to 25 µm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	.		
Wavelength (µm)	0.598		0.35 to 0.74 µm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (µm)	8.00		2.2 to 25 µm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.500		3 to 4
f/# Hard Code			
Wavelength (µm)	3.667		3 to 5 µm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	29.15	N/A	Calculated
Q	1.60	N/A	Calculated
Aperture Diameter Size (mm)	78.41	N/A	Calculated

Figure 90. Mid System 9 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	78.41	N/A	Given
Weight of System Optics (g)	199.75	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	2.0		1 to 20 mil
Theta (rad)	0.0020	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	7.85	N/A	Calculated
Sigma X (m)	9.31	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	8.91	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	0.67		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	59.2	N/A	Calculated
MicroElectroMechanical Systems Included	Yes	N/A	Yes, No
MEMS Improvement Factor	1.00		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	113.6	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	0.67		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	335.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 91. Mid System 9 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	0.80		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	67.7	N/A	Calculated
Electronics Improvement Factor	0.80		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	122.0	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	0.80		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	49.0	N/A	Calculated
Battery Improvement Factor	0.80		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	99.4	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	199.7	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	59.2	N/A	Given
MEMS Weight (g)	113.6	N/A	Given
Designator Module Weight (g)	335.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	67.7	N/A	Given
Electronics Weight (g)	122.0	N/A	Given
GPS Weight (g)	49.0	N/A	Given
Battery Weight (g)	99.4	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	807.6	N/A	Calculated
Total Weight (g)	2,794.4	N/A	Calculated
Total Weight (lbs)	6.2	N/A	Calculated

Figure 92. Mid System 9 Results (Part 3)

Overall Preference		0.6904
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	6.16
	Normalized Preference	0.3504
	Calculated Weight	0.2489
	Weighted Preference	0.0872
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1102
	Weighted Preference	0.1102
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	9
	Normalized Preference	0.6434
	Calculated Weight	0.4148
	Weighted Preference	0.2669
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 93. Mid System 9 Results (Part 4)

Step #1: Select technology timeframe

Attribute	Value	Sliders	Range
Technology Timeframe	FY24	N/A	FY14, FY19, FY24

Step #2: Select values for system attributes

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000		0 to 10,000 m
Recognition Range - Night (m)	2,500		0 to 10,000 m
Designation Range (m)	5,000		0 to 10,000 m

Step #3: Convert Recognition Range - Day to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Day (m)	5,000	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	2.00		0 to 12
Pixel Pitch (μm)	17.00		2.2 to 25 μm
Technology Type	Visible	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code	.		
Wavelength (μm)	0.598		0.35 to 0.74 μm
Target Angular Size (mrads)	0.46	N/A	Calculated
Pixel Angular Size (urads)	115.00	N/A	Calculated
Q	0.11	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Calculated

Step #4: Calculate Recognition Range - Day Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	40.0		0 to 250 g
Weight of Base System (g)	130.0		0 to 250 g
Aperture Diameter Base Size (mm)	30.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	49.28	N/A	Given
Weight of System Optics (g)	311.18	N/A	Calculated

Step #5: Convert Recognition Range - Night to Aperture Size

Attribute	Value	Sliders	Range
Recognition Range - Night (m)	2,500	N/A	Given
Target Size (m)	Standard (2.3 m)	N/A	0.7, 1.54, 2.3 m
Resolution	7.89		0 to 12
Pixel Pitch (μm)	6.00		2.2 to 25 μm
Technology Type	MWIR	N/A	Visible, SWIR, MWIR, LWIR
f/#	3.000		3 to 4
f/# Hard Code			
Wavelength (μm)	3.667		3 to 5 μm
Target Angular Size (mrads)	0.92	N/A	Calculated
Pixel Angular Size (urads)	58.30	N/A	Calculated
Q	1.83	N/A	Calculated
Aperture Diameter Size (mm)	34.30	N/A	Calculated

Figure 94. Far System 10 Results (Part 1)

Step #6: Calculate Recognition Range - Night Weight

Attribute	Value	Sliders	Range
Weight of Base Camera (g)	50.0		0 to 250 g
Weight of Base System (g)	140.0		0 to 250 g
Aperture Diameter Base Size (mm)	57.0		0 to 250 mm
Weight Power	2.50		2 to 3
Weight of Base Optics (g)	90.0	N/A	Calculated
Aperture Diameter Size (mm)	34.30	N/A	Given
Weight of System Optics (g)	25.29	N/A	Calculated

Step #7: Calculate Target Location Error Performance

Attribute	Value	Sliders	Range
Sigma GPS (m)	5.0		3 to 7 m
Sigma Range (m)	3.0		3 to 7 m
Theta (mil)	1.0		1 to 20 mil
Theta (rad)	0.0010	N/A	Calculated
Recognition Range - Day (m)	4,000	N/A	4,000 m
Sigma Azimuth (m)	3.93	N/A	Calculated
Sigma X (m)	6.36	N/A	Calculated
Sigma Y (m)	5.83	N/A	Calculated
Target Location Error (m)	7.18	N/A	Calculated

Step #8: Calculate Target Location Error Weight

Attribute	Value	Sliders	Range
Digital Magnetic Compass (DMC) Included	Yes	N/A	Yes, No
DMC Improvement Factor	1.00		0 to 1
DMC Base Weight (g)	32.9		0 to 250 g
DMC Weight (g)	32.9	N/A	Calculated
Celestial Included	Yes	N/A	Yes, No
Celestial Improvement Factor	0.50		0 to 1
Celestial Base Weight (g)	88.3		0 to 250 g
Celestial Weight (g)	44.2	N/A	Calculated
MicroElectroMechanical Systems Included	Yes	N/A	Yes, No
MEMS Improvement Factor	0.67		0 to 1
MEMS Base Weight (g)	113.6		0 to 250 g
MEMS Weight (g)	76.1	N/A	Calculated

Step #9: Calculate Designator Weight

Attribute	Value	Sliders	Range
Designator Included	Yes	N/A	Yes, No
Designator Improvement Factor	0.50		0 to 1
Designator Module Base Weight (g)	500.0		0 to 1,000 g
Designator Module Weight (g)	250.0	N/A	Calculated
Designation Range (m)	5,000	N/A	Given
Weight Power	2.50		2 to 3
Designator Optics Base Size (mm)	33.0		0 to 250 mm
Designator Optics Base Weight (g)	23.0	N/A	Calculated
Designation Base Range (m)	2,000		0 to 5,000 m
Designator Optics Weight (g)	226.8	N/A	Calculated

Figure 95. Far System 10 Results (Part 2)

Step #10: Calculate Fixed Weights

Attribute	Value	Sliders	Range
Laser Range Finder (LRF) Improvement Factor	0.72		0 to 1
LRF Base Weight (g)	84.6		0 to 250 g
LRF Weight (g)	60.9	N/A	Calculated
Electronics Improvement Factor	0.72		0 to 1
Electronics Base Weight (g)	152.5		0 to 250 g
Electronics Weight (g)	109.8	N/A	Calculated
Global Positioning System (GPS) Improvement Factor	0.72		0 to 1
GPS Base Weight (g)	61.2		0 to 250 g
GPS Weight (g)	44.1	N/A	Calculated
Battery Improvement Factor	0.72		0 to 1
Battery Base Weight (g)	124.3		0 to 250 g
Battery Weight (g)	89.5	N/A	Calculated

Step #11: Weight Roll-up

Attribute	Value	Sliders	Range
Day Imager Weight (g)	40.0	N/A	Given
Day Imager Lens Weight (g)	311.2	N/A	Given
Night Imager Weight (g)	50.0	N/A	Given
Night Imager Cooler Weight (g)	185.0	N/A	Given
Night Imager Lens Weight (g)	25.3	N/A	Given
Eyepiece Weight (g)	95.3		0 to 250 g
DMC Weight (g)	32.9	N/A	Given
Celestial Weight (g)	44.2	N/A	Given
MEMS Weight (g)	76.1	N/A	Given
Designator Module Weight (g)	250.0	N/A	Given
Designator Optics Weight (g)	226.8	N/A	Given
LRF Weight (g)	60.9	N/A	Given
Electronics Weight (g)	109.8	N/A	Given
GPS Weight (g)	44.1	N/A	Given
Battery Weight (g)	89.5	N/A	Given
Housing Percent Weight	0.289		0 to 1
Housing Weight (g)	667.0	N/A	Calculated
Total Weight (g)	2,308.1	N/A	Calculated
Total Weight (lbs)	5.09	N/A	Calculated

Figure 96. Far System 10 Results (Part 3)

Overall Preference		0.7701
Weight	Threshold Requirement	8.00
	Objective Requirement	2.75
	Expected Value	5.09
	Normalized Preference	0.5546
	Calculated Weight	0.2489
	Weighted Preference	0.1380
Recognition Range (Day)	Threshold Requirement	3,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.0800
	Weighted Preference	0.0800
Recognition Range (Night)	Threshold Requirement	900
	Objective Requirement	2,500
	Expected Value	2,500
	Normalized Preference	1.0000
	Calculated Weight	0.1102
	Weighted Preference	0.1102
Target Location Error	Threshold Requirement	25
	Objective Requirement	0
	Expected Value	7
	Normalized Preference	0.7130
	Calculated Weight	0.4148
	Weighted Preference	0.2958
Designation Range	Threshold Requirement	2,000
	Objective Requirement	5,000
	Expected Value	5,000
	Normalized Preference	1.0000
	Calculated Weight	0.1461
	Weighted Preference	0.1461

Figure 97. Far System 10 Results (Part 4)

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